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REPORT ON NEW MATERIALS AND NEW USES OF MATERIALS IN CONSTRUCTION OF WATER AND WASTE COLLECTION, DISTRIBUTION AND TREATMENT SYSTEMS, AND IN WATER QUALITY CONTROL TO THE SENATE COMMITTEE ON PUBLIC WORKS

PUBLIC HEALTH SERVICE, WASHINGTON, D.C.

1962

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The Committee on Public Works, in executive session on January 16, 1962, approved a committee resolution authorizing hearings, study, and a report on the use of materials in the construction of buildings, roads, water resource projects, and other public works. This report offers comprehensive data on: design and construction of water distribution systems; maintenance of water treatment plants; water treatment plant operation and maintenance; design and construction of sewage and industrial waste collection and treatment systems and works; research on water reuse feasibility; and comprehensive water quality management.

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Report on

NEW MATERIALS AND NEW USES OF MATERIALS IN CONSTRUCTION OF WATER AND WASTE COLLECTION, DISTRIBUTION AND TREATMENT SYSTEMS, AND IN WATER QUALITY CONTROL

to the

SENATE COMMITTEE ON PUBLIC WORKS

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

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United States Senate
COMMITTEE ON PUBLIC WORKS

February 27, 1962

Honorable Luther L. Terry
Surgeon General
Public Health Services
Department of Health, Education,
and Welfare
Washington 25, D. C.

Dear Mr. Terry:

The Committee on Public Works, in executive session on January 16, 1962, approved a committee resolution authorizing hearings, study, and a report on the use of materials in the construction of buildings, roads, water resource projects, and other public works.

To attain the objective of the committee, it will be most helpful if we could obtain the cooperation of industry and the Government agencies in the collection of information called for by the resolution; therefore, it will be appreciated if you will supply us with such information as is related to your interest or activity.

A copy of the resolution is enclosed for your information. If you require further details, please contact Mr. John L. Mutz of the committee staff who is in charge of handling this particular study.

I believe that with the new materials and new uses of known materials being developed and utilized, we should be able to gather considerable information on this subject; thereby making an extremely interesting and constructive contribution to the various producers, fabricators and users of materials. Furthermore, it would be most useful and helpful if we were to obtain information with respect to new designs and new methods of installation of materials.

It is my hope that your organization will be in a position to appear before the Committee on Public Works to make a formal presentation during the early part of April, 1962. After the hearings or presentations are completed, it is planned to have a committee report prepared thereon and submitted to the Senate.

I would appreciate it if you would advise me if you will be able to complete such a report for presentation to the committee at the suggested time, so that we may set tentative dates for the hearings.

Sincerely yours,

Dennis Chavez

Dennis Chavez
Chairman

DC/jmt

Enclosure

87th. Congress

2nd. Session

UNITED STATES SENATE

Committee on Public Works

COMMITTEE RESOLUTION

PROVIDING FOR A STUDY AND INVESTIGATION OF USE OF MATERIALS IN PUBLIC WORKS

WHEREAS, The Senate Committee on Public Works has under its jurisdiction measures relating to flood control and rivers and harbors, roads, and highways, public buildings, water pollution control, water power and other matters relating to developments within the Nation; and

WHEREAS, the Senate Committee on Public Works has authority to make investigations into any matter within its jurisdiction; and

WHEREAS, the Senate Committee on Public Works members have been vitally interested in the development, protection and utilization of our Nation's water resources as evidenced by their active participation in the hearings and deliberations of the Senate Select Committee on National Water Resources; and

WHEREAS, there are now being produced and our scientists and technicians, both in industry and Government, are working on and perfecting many new materials and new uses of known materials and it is evident that such materials can be utilized efficiently and economically in the construction of public works, in the protection and operation of such works, in the preservation and proper utilization of our essential water resources and that such materials and their development and use enhance the opportunities for industrial and business growth and strengthening of our Nation's economy; and

WHEREAS, representatives of industry and the Federal Government have shown a keen interest in discussing and disclosing their roles in the fields of research, development and utilization of materials.

Therefore, be it Resolved, by a unanimous vote of the Senate Committee on Public Works that the Committee shall institute a study and investigation into the use of new materials, new use of materials and new designs and methods being used or which may be used in flood control and rivers and harbors, roads and highways, public buildings, water pollution control, water power and other development, utilization, preservation and protection projects, and that a committee report be prepared thereon and submitted to the Senate.

Sec. 2. Such study and investigation shall include but not be limited to metals, plastics, rubber, coal, petroleum, timber, concrete, asphalt, chemicals and their direct use, uses of their derivatives or use in combination with each other or other materials, and shall attempt to determine the following:

(a) Description of proposed use of application of the subject material;

(b) General description of the materials in terms of physical and chemical characteristics and where possible, obtain a description of the physical or chemical phenomenon responsible for obtaining the desired effect;

(c) Results of laboratory and field tests to prove that the desired effect occurs and prove the durability or duration of the effect of the material;

(d) The limitations of the materials, i. e., problems of toxicity, limitation of effectiveness under certain climate, soil or physical conditions;

(e) Cost of materials per standard units, i. e., square foot, lineal foot, cubic foot, etc., and cost projection in terms of future production capacity, improved manufacturing techniques, etc.; and

(f) Availability of material both on a current and future basis.

Adopted: January 22, 1962.

Chairman

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE
WASHINGTON 25, D.C.

Refer to:

MAY 1 1 1962

Dear Senator Chavez:

In accordance with your request of February 27, 1962, a report on "New Materials and New Uses of Materials in Construction of Water and Waste Collection, Distribution, and Treatment Systems and in Water Quality Control" has been prepared and is enclosed herewith for the use of the Senate Committee on Public Works.

Since water quality management involves major research and comprehensive program planning for river basins, as well as major construction of public water and sewerage works, these subjects have been included in our report insofar as they deal with new materials and new uses of known materials.

We appreciate this opportunity to be of service to you and the Committee on Public Works. If further information is needed, please advise us. We will be prepared to make whatever presentations are required at the Committee hearings.

Sincerely yours,

John D. Porterfield
Acting Surgeon General

Honorable Dennis Chavez
Chairman, Senate Committee on
Public Works
United States Senate
Washington 25, D. C.

Enclosure

NEW MATERIALS AND NEW USES OF MATERIALS IN CONSTRUCTION OF WATER AND WASTE COLLECTION, DISTRIBUTION, AND TREATMENT SYSTEMS AND IN WATER QUALITY CONTROL

Report of the Public Health Service of the
Department of Health, Education, and Welfare
on Use of New Materials in Water Resources
Supply, Development, and Protection of the
Senate Public Works Committee

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NEW MATERIALS AND NEW USES OF MATERIALS IN CONSTRUCTION OF WATER AND WASTE COLLECTION, DISTRIBUTION, AND TREATMENT SYSTEMS AND IN WATER QUALITY CONTROL

Report of the Public Health Service of the
Department of Health, Education, and Welfare
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Supply, Development, and Protection of the
Senate Public Works Committee

INTRODUCTION

The present economic and community development of this country would have been impossible without the modern water distribution and sewage collection systems which serve the cities of the Nation. These utilities are vital in the support of large concentrations of people, commerce and industry, and to our present high standards of living, health, and way of life.

One can only speculate on what conditions of filth and disease would prevail in cities like Chicago, New York or Los Angeles if there were no sewage collection systems. Without water distribution systems, present population densities could not be supported, fire protection would be incredibly difficult, and waterborne disease would be rampant as it was in the 19th century before the advent of the modern water purification plant. The new home of today, replete with multiple baths, automatic laundries and dish washers, and garbage disposals, would be but an architect's dream.

As it is, the modern water distribution system delivers clean, safe water to the farthest point in the community and to the top floor of the highest buildings at an average cost of 17-19 cents per 1,000 gallons, or less than five cents per ton. After use, this water is collected by the sewerage system and conveyed away to a point of disposal at a cost averaging four cents per 1,000 gallons. In most cities the sewage is treated at least to some degree before discharge to a watercourse, and this service averages about 4-6 cents per 1,000 gallons. Water supply and sewage collection are the cheapest of all utilities, and so efficiently and reliably provided that the average consumer seldom realizes how dependent he is upon them.

Although water supply and sewage collection systems are the cheapest of utilities, they represent collectively a very large dollar investment. The following table shows the investment requirements for municipal water and sewerage facilities for the period 1958 - 1980:

PRESENT AND PROJECTED INVESTMENT REQUIREMENTS FOR MUNICIPAL WATER AND SEWERAGE FACILITIES, 1958 - 1980

(in billions of 1958 dollars)

	In Existing Facilities as of 1958	Estimated Backlog of Needs 1958	Required for New Growth 1958 - 1980	Required for Obsolescence of Facilities 1958 - 1980	Total Cost of Needed Construction 1958 - 1980
Municipal Water Facilities1/	33.6	2.7	22.4	18.5	43.6
Municipal Sewerage Facilities2/	25.0	5.0	22.5	22.0	49.5
TOTAL	58.6	7.7	44.9	40.5	93.1

1/ Includes source development, distribution systems and water treatment facilities.

2/ Includes sewage collection system, interceptors, outfalls, and sewage treatment facilities.

In view of the magnitude of investments to be required within the next 20 years, it is essential that the design and construction of water supply and sewerage systems provide for the maximum service at the minimum cost. This will require a continuing search for new, more effective design criteria, construction materials, and procedures. Once in place, such systems require continuing operation and maintenance, with a need to develop the best chemicals, materials, equipment and instruments to assure continuous service and to protect a very large investment that is largely buried underground.

Since 1900, the number of communities served by sewers has increased from 950 to more than 11,000, and the number of persons served by sewers has risen from 24.5 million to more than 105 million. In 1960 the municipal wastes discharged to streams had a pollutional effect equal to the untreated sewage from 75 million people, three times the amount in 1900. Pollution from water-using industries has increased even more. In 1960 organic industrial wastes were estimated to have a population equivalent of 150 million persons, and in addition there are large amounts of inorganic wastes (of mineral and chemical origin) not measurable in terms of sewage (as population equivalent).

During this same period fresh water use has leaped enormously. Since 1900, it has increased eight-fold--from 40 billion gallons a day to the present more than 325 billion gallons a day. By 1980 water needs are expected to reach 600 billion gallons a day, and by the year 2000 the daily need will be well over 1,000 billion gallons. Since present water use already exceeds the developed supply in many areas, and 650 billion gallons per day appears to be the maximum dependable supply we can ever hope to develop, it becomes apparent that water needs can be met only by the reuse of the same waters.

Both the increase in fresh water use and the increase in water pollution are a direct result of population and industrial growth. Obviously, increasing pollution is in direct conflict with the need to reuse water. This conflict must be resolved through the development of scientific water quality management programs for entire river basins, and much more effective waste treatment processes than exist today.

Such water quality management programs must be designed to conserve and protect all beneficial water uses by their ability to deliver the required quality of water at the times and places where it is needed. They must be designed to measure and evaluate all of the variables affecting water quality management decisions, both immediate and long range.

The development, design and operation of scientific water quality management programs for river basins will require the development and application of computer systems, hydraulic and mathematical models, automatic instruments, telemetering systems, and a wide variety of other data collection, evaluation, and storage procedures and equipment. Reliable methodology for detecting water pollutants, particularly those resulting from new technology, and for measuring their effects on water uses is required. Valid procedures for projecting economic and demographic growth are essential to the long range applicability of water quality management programs, currently being planned to cover a period of 50 years.

The concentration of population and industry in urban areas is already creating serious water pollution problems from the vast amounts of complex wastes being discharged into limited water resources, even where these wastes are treated. Chicago serves as a typical example. Although the city provides the best treatment as now practiced, the daily treated effluent is equivalent to the raw sewage from one million persons and contains solids amounting to 1,800 tons, causing serious pollution downstream in the Illinois Waterway.

It is already apparent that industrial and municipal wastes and surface and ground waters are undergoing important changes in composition. Products of our chemical technology are finding their way into our waterways in ever-increasing amounts and in more and more locations as chemical plants increase in size and number, and as their products are increasingly used in the home, in industry, and in agriculture. Synthetic detergents, pesticides of all kinds, and various petro-chemicals are examples of these contaminants which are resistant to modern waste treatment and to destruction by natural stream purification processes. Therefore, these substances may persist almost indefinitely in the receiving streams. Existing water purification processes are not reliable in removing these persistent materials. Our best methods for detecting and identifying these contaminants are only partly effective.

Studies of treated municipal wastes have emphasized the fact that modern treatment methods cannot remove all the soluble compounds present in the incoming sewage. Spot surveys at Toledo, Cleveland, Boston, and Detroit showed that a single municipal use of water produces an average increase of about 250 ppm of inorganic solids and 175 ppm of volatile solids. The concentration of inorganic materials is not appreciably affected by sewage treatment, and even highly treated sewage plant effluents still contain 50-150 ppm of organics based on the volatile solids test.

In the face of a naturally fixed water supply, the growing needs of expanding population and industry will require that water be used over and over. Reuse of water already is well established in some areas; it will appear in others also. Eventually reuse will become an accepted and necessary practice in most densely populated areas. Reuse of water will not be possible in densely populated and industrialized areas or in water-short areas unless much more effective treatment processes are developed. These new treatment processes will need to be based on chemical-physical separation principles, capable of achieving an actual conversion of waste waters to fresh water. This will require major research that is already underway and discussed in succeeding sections of this report. The design, construction, operation and maintenance of these new separation systems will require extensive use of new procedures, equipment, materials, instruments and chemicals.

THE DESIGN AND CONSTRUCTION OF WATER DISTRIBUTION SYSTEMS

General

A waterworks distribution system includes pipes, valves, hydrants, and appurtenances for conveying water; reservoirs for storage, equalizing, and distribution purposes; booster pumping facilities; pressure control devices; instrumentation and control; service pipes to consumers; meters; and all parts of the conveying system after the water leaves the main pumping station or the main distribution reservoirs.

Planning of water systems calls for careful consideration of current and possible future trends in the use of urban land. The criteria of 15 or even 10 years ago may no longer apply. Historically there has been a continual increase in the standard of living in the country. With this trend have come the use of many new appliances to make life easier and more comfortable, such as automatic dishwashers, garbage disposals, water cooled air conditioners, home washing machines, and swimming and wading pools. Also the trend in residential housing with more spacious living has created increased sprinkling demands.

Furthermore, the demands of the outlying districts are no longer governed strictly by residential requirements. Industries are moving out of congested traffic areas and the shopping public has become more adverse to frequent trips downtown. This affects the distribution of the fire-fighting demand. The peak rates of residential consumption are often several times the average daily rate, and the pattern of usage has been changing in recent years.

The Problems Involved

The above use and demand factors must be evaluated in the selection and sizing of pipe, in addition to the cost of purchasing the pipe and laying the mains. Related to the problems of sizing mains are those of selecting materials which will minimize the corrosiveness of the water conveyed and of the soil surrounding the pipe.

Design and construction must include a thorough evaluation of high pressure requirements, conditions of high beam and crushing loads, abnormal shocks and stresses, and bedding conditions in which the piping system is to be laid. These factors are related to initial cost, maintenance costs, and continuity and quality of service.

The principal problems involved in providing distribution storage are to determine the capacity required and to establish a location that will serve the system effectively as well as avoid offense to the neighborhood.

The big change in peak water consumption rates has brought about reconsideration of factors which govern pressures in the distribution system. It is not easy to provide pumping and processing capacity to keep pace with these factors, much less that of instantaneous demands. The balancing of availability with demand must come from storage, both on the ground and elevated.

Traditional Design and Construction Practice

The materials most commonly chosen in the past for distribution system pipes include cast iron, steel, concrete, and asbestos-cement.

Cast iron pipe has been the most generally used material in distribution practice in sizes up to 24-inch. It is generally made by centrifugal casting in either metal or sand-lined molds. The use of seal-coated spun cement linings has effectively controlled loss in carrying capacity due to corrosion and tuberculation. Although there are about six general classes of field joints for cast iron pipe, bell-and-spigot joints have been standard for years. They are generally made in accordance with the specifications of the American Standards Association and the American Water Works Association. Bell-and-spigot joints are poured with melted lead and caulked after pouring, poured with a sulfur base compound, or caulked with lead wool or portland cement.

Reinforced concrete, as used for pressure conduits, especially those of larger diameter, offers the advantages of continuously high capacity, and with the currently used rubber ring joint, a low rate of leakage. The pipe is usually made at or near where it is to be laid, using local labor and local materials insofar as they are available. It is made in sizes from 16-inch up to 13-foot diameter, and for pressures up to 250 pounds per square inch. The joints of these pipes are made with a more or less modified bell-and-spigot. The usual designs include steel bell-and-spigot rings, with a sealing element made of either lead or rubber. There are several A. W. W. A. standards for concrete pipe, including reinforced concrete steel cylinder pipe, prestressed and non-prestressed and reinforced concrete pipe, non-steel cylinder and non-prestressed. In steel cylinder pipe, the steel cylinder is continuous and is welded to the joint rings, thus forming a continuous steel water seal throughout the length of the pipe. Concrete pipe fittings are available.

Asbestos-cement pipe is made of a mixture of asbestos fiber, portland cement and silica, formed under high pressure into a dense, homogeneous structure. The pipe is available in diameters of 3 inches to 36 inches and for working pressures up to 200 psi. The pipe is said to be free from both internal and external corrosion, tuberculation, electrolysis, and has good hydraulic characteristics. Joints consist of an asbestos-cement sleeve with two roll-on or slip-on rubber rings. Compatible fittings are available in cast iron and in copper for small sizes.

Steel pipe is made from the smallest size to several feet in diameter, and in lengths up to 50 feet or more. Normally it has not been used in water distribution system practice in sizes 12 inches in diameter and under. Fittings are generally fabricated by welding. Joints may be welded or of the bolted rubber-ring, sleeve type such as Dresser couplings. Steel pipe generally is lined with cement mortar or coal tar enamel in order to minimize corrosion and tuberculation. Exterior coatings generally are coal tar enamel, although cement mortar coatings have been used.

Other materials used for distribution piping include wrought iron and plastics.

Valves are a necessary part of a water distribution system since they serve to isolate a section of the system in the event of a main break, thereby minimizing the damage which would be caused by an unrestricted flow of water. Valves are also used to facilitate repairs and to permit cut-ins for new mains and services.

Aside from completely stopping flow, valves are used for throttling or controlling quantities of water flowing in a pipe. Other uses include pressure and level control and proportioning flow. They may function automatically, actuated by pneumatic, hydraulic, or electrical control systems.

The types of valves in common use in water distribution systems include gate, globe, rotary, butterfly, pressure reducing, and check valves, as well as several other kinds.

Storage capacity is determined by consideration of: (1) the reserve required to meet standby operations, often sized by fire insurance regulations, (2) growth and development of the area served and present and future rates of water use, (3) the feasibility of maintaining the reserve volume of water desired at the contemplated elevation for pressure maintenance, and (4) the adequacy of the supply.

Elevated and ground storage tanks and standpipes are utilized to aid in supplying water demand and maintaining pressure in the system. They are constructed of steel or concrete and their design involves primarily structural considerations after capacity and location factors are determined. Ease of maintenance is highly important, as is protection against deterioration. In residential locations, the designer should never overlook esthetic considerations, involving to a great extent the appearance of the structure.

One other important part of the water distribution system is the meters which are installed. There are two principal objectives in metering: (1) providing an impartial record of the water consumed, and (2) equitably dividing the cost of rendering service. The water meters used in a municipal water system to measure the flow to customers are known as service meters; those measuring the flow to or in the distribution system as main line meters.

The characteristics which are of special importance in service meters are accuracy and sensitivity, both when new and after use; durability; low pressure loss; cost of purchase and installation; ease and low cost of maintenance. There are three basic types of service meters normally used. These are the disc meter, the oscillating piston meter, and the turbine meter. Where extreme rates of flow are experienced by large customers, a compound meter is used combining the disc or piston meter with the turbine type. Main line meters may be propeller or venturi type.

New Materials, Equipment, and Designs and The New Application of Older Materials, Equipment and Designs

One of the major advances in the water works field in recent years has been the use of computers by engineers for analyzing existing distribution systems and designing new ones. What used to be a time-consuming and complicated process, particularly with existing systems, has been greatly simplified by employing both the McIlroy Network Analyzer and the digital computer. At the present time four water utilities in large metropolitan areas own McIlroy Analyzers, and use them as a tool for determining the best manner of supplementing their systems in the areas presently served and of serving new areas.

Today there is available a wide choice of pipe materials permitting considerable latitude in designing a system specifically for the job it is to do and the conditions which will be encountered. There are several new kinds of pipe and ways to put them together.

One of these new types of pipe is ductile iron, which is cast iron in which graphite is present as spheres or spheroids as compared with flakes in gray cast iron. It has the property of permitting bending and twisting without breaking, and is recommended for use under conditions of high pressure, extreme beam and crushing loads, unusual shocks and stresses, and unstable bedding conditions, all of which contribute to breakage.

There are a number of types of plastic pipe which are produced in 1/4 inch to 12-inch sizes by the extrusion of thermo-plastic materials, and are available in flexible, rigid, and semi-rigid forms. All of the types recommended for use in domestic water supplies are said to be non-toxic and to impart no taste or odor to water. They are inert and not affected by aggressive soils or electrolysis, but their use is not recommended for temperatures above 120 degrees F.

There are also available new machines for casting concrete pipe in place by the slip-form method. One of these operates in an excavated trench and consists primarily of a traveling form with facilities for distributing and vibrating the concrete as it is poured. Concrete is supplied to the machine hopper by transit mixers. Equipment is available to construct pipe 24 inches to 60 inches in diameter at a maximum depth of 16 feet. Another manufacturer provides equipment for field casting of concrete in place for diameters of 12 inches to 30 inches. The process includes an inside form which is inflated for use and deflated for pulling forward as soon as the concrete has taken its initial set. A tamping device is provided to insure a complete fill of uniformly placed concrete. There is also available a concrete pipe casting machine, for sizes 24 inches to 120 inches, using aluminum interior forms, with outside forming provided by the trench. This type of cast-in-place pipe is not suited to distribution system pressure requirements, but could be used for gravity supply lines.

Laying procedures have changed greatly with the advent of the slip-type joint. Several manufacturers of cast iron pipe have pioneered the slip or push-type joint which involves the use of a rubber gasket molded to conform to ridges cast in the pipe bell (a similar development has taken place for concrete pipe). To make the joint in the field, the gasket is inserted in the bell, the spigot end is treated with a thin film of lubricant, and the spigot is then merely pushed "home". Considerable savings in time and labor are effected by this method.

Conventional concrete water storage tanks have been in use for over 50 years. In recent years, reinforced concrete water tanks have been designed and built as prestressed structures. Prestressed tanks can be built in capacity ranges of 100,000 to 30,000,000 gallons.

A new method of controlling the speed of wound rotor motors for variable speed pumping has been developed, using a new device that is essentially a water rheostat. The drive motor speed is controlled by the use of a series of stainless steel plates in a two-compartment container. These resistors are wired into the rotor circuit of the wound rotor motor. The submergence of the plates is determined by the pressure at some control point in the system, and the design of the shape of these resistor plates is such that the pump motor operates at a speed which will produce a predetermined pressure level at the control point in the system.

The development of the submersible motor and its adaptation to well pump operation has led to the use of the submersible pump for booster service. Both vertical and horizontal types are in use. Some have been buried without benefit of a service vault. They permit an installation to be made completely within public rights-of-way and require only the control to be located above ground. It can usually be mounted on the power service pole.

Most water utilities have found that as the areas they serve have expanded and commercial districts have been decentralized, the load factor has become more and more important in providing adequate water service. In order to have an accurate basis for charging customers for a high demand load, research has been underway to develop a demand meter. Some firms are now offering equipment which will register peak loads reliably with reasonable expense.

The next step is improvement of metering application to facilitate reading. The manpower required to examine registers every time a customer is billed is costly. Remote registering to avoid periodic invasion of basements is an improvement. Magnetically and cable-driven registers can be designed for positioning on the outside of the premises to be read easily and even removed, if necessary.

Instrumentation has advanced to the point where nearly any process can be observed and controlled from a central or remote location. Pressure in the line and liquid levels can be observed; pumps can be programmed to keep pace with the rate of use; and valves can be opened and closed. For maximum efficiency, modern water works practice should take advantage of these and other automatic possibilities.

Cost will continue to be a major factor in the design and construction of water systems. Research should be continued to improve construction materials and procedures, to improve demand and pressure controls, and instrumentation.

Note: Since the design and construction of water distribution systems must necessarily be responsive to the problems in their maintenance, much of the above applies also to the following subject which deals with maintenance.

MAINTENANCE OF WATER DISTRIBUTION SYSTEMS

General

The distribution system of a water utility represents 60 to 75% of the total value of the entire facility. Maintenance and operating costs of this part of the utility are about 15 to 20% of total costs (excluding taxes). In the period 1951-60, mileage of mains in service has increased approximately 23%, customers have increased 20.6%, but the number of customers per mile of main (3.7) has changed little.

It is estimated that 65% of the water lines now being installed are of ferrous materials, with concrete mains and cement asbestos lines accounting for 5% and 30%, respectively. Transmission mains are approximately 50% concrete and 50% steel. Approximately 80% of the cast iron and steel being installed is cement lined. Since no water pipe was lined with cement until in the 1920's, there are in the country's water distribution systems many miles of unlined mains which are inadequately protected against corrosion. These probably amount to 10% of the mains in use.

The Problems Involved

Breaks and Leaks - Among the most troublesome problems in the operation and maintenance of distribution systems are main breaks and joint leaks which waste water, damage streets, other utilities, and customer property. Philadelphia has an average of 770 main breaks a year, an average of 25 per 100 miles of main. The incidence of main breaks in this city has been as high as 1,000 with 300 occurring in one month. New York City has an average of 330 breaks per year, 20 of these in lines 20" in diameter or larger. Other cities suffer similar experiences.

External forces and external corrosion are more important factors in main breaks than age of pipe and internal corrosion, although older pipe has been found more subject to breakage. Longer centrifugally cast pipe is reported more apt to break than standard 12' lengths of pit cast iron. The corrosive action of sulfur jointing compounds may contribute to breakage. Pressure increases contribute to breakage; for example, an increase of but 10 pounds per square inch in Philadelphia resulted in 18 breaks in a single hour.

Corrosion - It is generally assumed that cast iron pipe does not seriously deteriorate from exterior corrosion conditions. However, old pipes taken from the Philadelphia system show materially reduced wall thickness and in Winnipeg, Canada, soils have been found to be sufficiently corrosive to cause pipe failure. A 45-year study of underground corrosion by the National Bureau of Standards estimates the annual cost of protective measures and replacements due to exterior corrosion in the country's one million miles of gas, oil and water lines to be $600 million. Penetration of steel pipe by pitting has led to its replacement in many areas.

Water cannot be made entirely non-corrosive, although its corrosiveness can be lessened or mitigated. With an estimated 10% of the average water distribution system in unlined cast iron lines, corrosion troubles can be expected to occur since the disintegration of the original tar coatings leaves exposed metal surfaces. Such corrosion can result in "red water" and staining of clothes and industrial complaints. Red water difficulties are relatively easy to correct with water treatment. The problem of reduced carrying capacity resulting from tuberculation and rust deposits within water mains still eludes solution. The estimated cost of reduced water main carrying capacity due to tuberculation and deposits caused by corrosion is about $40,000,000 a year.

Mains cleaned by mechanical devices deteriorate rapidly after such cleaning in most cases, the decrease in carrying capacity sometimes amounting to 35% within three months after cleaning. The deterioration in new tar coated pipe by corrosive waters is considerably less but has amounted to loss of 25% capacity within 5 years.

Deposits - Chemical deposits from the water carried in pipe lines also causes loss of carrying capacity; for example, calcium carbonate laid down from an unstable, softened water and deposits caused by oxidation and precipitation of manganese.

Freezing - Extreme cold weather always results in some freezing of water mains and services. The problems involved are less than formerly was the case as newer mains are laid to greater depths. The magnitude the problem can attain is shown by the experience of Knoxville, Tennessee, in February 1958, when in 8 days the Water Department handled 2,034 complaints of frozen service lines, frozen pipes on private property, and frozen meters. There were also 78 breaks in main lines.

Maintenance of Pressure and Storage - All water systems seek to maintain adequate pressure, generally between 50 and 80 psi. The National Board of Fire Underwriters allows some credit for residual pressures in excess of 60 psi and in some cases 75 psi. System pressures should preferably be below 100 psi.

Maintaining uniform pressure is a difficult problem because of the wide range in water requirements during high peak-demand periods. Lawn watering, air conditioning, refrigeration, industrial demands and human habits are among the factors which create peak demands on water systems.

Combined effects of various water uses increase storage requirements by 10 to 25%. Maximum hourly draft rates expressed as % of the maximum day rate for certain uses are: lawn sprinkling - 37-70%, air conditioning-22-32%, and combined uses - 48-127%. The problem is to provide storage which will handle peak demands within reasonable cost bounds. A rule of thumb quantity to eliminate severe hourly peaks is 15 to 20% of the average daily consumption, with 20% being favored.

Cross Connections - Cross connections with industrial and domestic supplies continue to be a problem of distribution system management. The potential hazards from cross connections may be grouped into three main classes: (1) pollution of the general distribution system as a result of improper construction or faulty operation; (2) pollution by backflow connections or through interconnections with plumbing fixtures, waste water disposal systems, or equipment conveying or containing harmful liquids or non-potable water or water subject to pollution; and (3) pollution through cross connections with other supplies.

Valves - Gate valves offer another problem of distribution system maintenance and many operators feel that this problem can only be solved by the design of an entirely new type of valve. Corrosion and deposition of material on the bottom and the valve seats cause the wedges to wear. A large part of distribution maintenance expense (which can be as high as $725.00 per year per mile of mains) is chargeable to valve maintenance and repair.

Traditional Practices

Flushing Programs and Corrosion Control - Most smaller and medium size water systems flush thoroughly their distribution systems once or twice a year. In larger systems this is not practical and flushing is limited to area flushing as required. Active corrosion can result from flushing if the velocities result in removing the protective deposits which seal the mains.

Leakage Surveys - Most water departments keep a rather close check on "unaccounted for water". Hydrants and lines are checked with leak-detecting instruments which electronically intensify the sound of flowing water. At least one corporation conducts, professional system leak surveys which have produced considerable savings.

An "unaccounted for" figure of more than 15% should be cause for concern and any sudden increase in the percentage should signal a search for leaks. A system that accounts for 90% of water input is considered a "tight" system.

Cross Connection Studies - A great deal of work and expense goes into the protection of public water supplies and all can be undone if the distribution system is not continuously protected. Waterborne diseases have been virtually eliminated in this country by the practice of good water supply sanitation. The possibility that practice can yet be improved is exemplified by the few outbreaks continuing to occur as the result of inadequate protection in distribution systems.

Responsibility for programs to control or prevent cross connections usually rests with the owner of the property served and with local or State agencies having jurisdiction over building and residential plumbing, seldom by the water purveyor.* However, inasmuch as the large majority of city water systems are publicly owned, overall jurisdiction is in a Government agency or head of government such as city, county, or State.

Practice has leaned toward connections in a manner permitting no possibility of backflow or siphonage, e.g., no direct connection. However, equipment is available and in use which can be maintained and gives acceptable assurance of working under all operating conditions. The extent of use of this and new equipment depends greatly upon the programs responsible for plumbing and water supply protection, including definite schedules for surveillance of the protective devices installed.

The Use of New Materials and Equipment and New Uses of Older Materials and Equipment

Many new materials and new equipment are being developed for use in water distribution systems, and are disucssed above under design and construction. All are designed to overcome one or more maintenance problems--costs, corrosion, leakage, pressure maintenance and others.

Plastic Pipe - The use of plastic pipe in the water works field dates from 1950 or 1951. From a maintenance standpoint, the advantages of plastic pipe are indicated to be good resistance to chemicals, electrolytic attack and inorganic corrosive materials; lightness of weight; and smoothness of surface. Disadvantages include low mechanical strength, sensitivity to temperature (brittle when cold, weak above 140°F) and being subject to time dependent properties (low rupture stress, high creep values).

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* The division of responsibility for water supply protection is recognized in the Public Health Service Drinking Water Standards by the following statement, "---responsibility for the conditions in the water supply system shall be considered to be held by: (1) The water purveyor from the source of supply to the connection to the customer's service piping; and (2) The owner of the property served and the municipal, county, or other authority having legal jurisdiction from the point of connection to the customer's service piping to the free-flowing outlet of the ultimate consumer."

Membrane Filter - Good sanitary engineering practice requires disinfection of newly laid water lines. Before releasing such lines for service, a bacteriological test is necessary. The old test took up to four days while the new membrane filter method of bacterial analysis has reduced this period to eighteen hours.

Leakage and Breakage - The new kinds of pipe jointing systems and new pipe materials show promise of alleviating the very troublesome maintenance problems caused by leaks and breaks in the distribution system. Experience thus far has shown a number of these jointing systems to be flexible, leakproof, and resistant to corrosion. New pipe materials are also being designed to reduce breakage and corrosion, and of these ductile iron is reported to show considerable promise.

Corrosion Control - Polyphosphates continue to be effective in controlling corrosion of cast iron pipe. Recently, a zinc polyphosphate has been made available and found very effective in preventing excessive corrosion of freshly cleaned cast iron pipe. A rapid method (3 to 4 hrs.) for laying a smooth calcium carbonate coating on the surface of pipe cleaned and mechanically scraped has also been devised. Depending on the water analysis, the chemicals used may be calcium chloride, soda ash, caustic soda, or sodium hexametaphosphate.

Great strides have been made in the control of corrosion caused by electrolysis through the efforts of cooperative, area corrosion committees. This type of corrosion has in some areas been largely corrected by mechanical bonding of all underground utility structures. The change from streetcars to buses has hastened this improvement. The use of cathodic protection for steel pipe (exterior), steel water storage tanks, and steel purification facilities has greatly increased. Protection is gained through use of steel, carbon, and magnesium anodes and rectifiers of various types, and by the use of buried anodes without current.

Paint and Protective Coatings - Until recently, poor success had been obtained with paints for interior protection of steel structures such as ground-level water storage tanks, elevated tanks, and basins in purification plants. Experience with numerous steel tanks indicates that when phenolic type paint systems are used, painting must be repeated every two or three years. Currently, red-lead phenolic paint systems are being replaced by zinc dust-zinc oxide phenolics, aluminum phenolics, vinyls and epoxies. Vinyl paints appear to be the most promising of the newer coatings, all of which provide improved protection.

For exterior tank painting, good results have sometimes been obtained in the primer coat with easy-to-use conventional paints, such as red lead-linseed oil-alkyd mixtures. For final coats, aluminum paints give excellent results, and colored aluminum is a recent introduction. Vinyl, epoxy, and chlorinated rubber paints can be used for final coats. An eight-year service life may be obtainable from vinyl paint systems.

Communications for Central Control - In October 1958, there were more than 2,000 utility radio licenses involving water departments. Among the advantages of radio systems in a water utility are improvement in consumer service, speed-up in handling emergencies, improvement in employee morale and increased employee productivity. Transistorized equipment is replacing units with tubes which required replacement every 7 to 10 years.

Control centers for remote recording and control of pumping rates, pressures, water levels and other data, are a relatively new development in the water works industry being widely accepted. Equipment used for these systems includes: electric sensing devices called "transducers"; various telemetering instruments from assembly points for the required electric analog signals; other devices to change analog to tone signals; microwave towers; converters for changing tone signals to microwave; equipment to reconvert microwaves to tone; and electronic deciphering equipment.

Consumer Service Materials - Consumer service lines are now constructed principally of copper, although various plastic materials are extensively used also. Little trouble has been experienced with these new materials after some initial failures due to thin pipe and use of plastic adapters. Brass adapters with stainless steel clamps are now used. Type L copper is being substituted for type K, on the theory that failure of copper through corrosion will not be prevented by the slight additional thickness of type K.

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THE DESIGN AND CONSTRUCTION OF WATER TREATMENT PLANTS

General

No matter whether the source of a municipal or industrial water supply is surface water or ground water, it is almost impossible to meet all modern requirements of water quality without some form of treatment. These requirements will vary, depending upon the use of the water, but ideally they would be as follows:

1. The water shall be free from disease-producing organisms.
2. The water shall be sparkling clear and colorless.
3. The water shall be palatable, free from odors, and preferably cool.
4. The water shall be reasonably soft.
5. The water shall be neither scale-forming nor corrosive.
6. The water shall be free from objectionable substances, such as hydrogen sulphide, iron, and manganese.
7. The water shall not contain substances in quantities which are toxic or which have adverse physiological effects.
8. The water shall be available in ample quantities and at a reasonable cost.

The Problems Involved

One of the first steps to be taken in the design of a water treatment works to meet the above criteria is the estimation of the quantity of water required. This estimate must, of necessity, be an approximation since it applies to some future date. The factors to be taken into account include domestic usage, commercial and industrial usage, public usage and losses, variations in water demand, fire demand, and the amount of storage available or to be provided.

The quality of the water required by the consumers and the quality of the source are the next consideration. These factors determine the type of plant which must be designed and constructed. Generally, the plant must be designed to produce treated water which will at least meet the U. S. Public Health Service Drinking Water Standards, as revised in 1961. Also to be considered are certain industrial uses which have higher quality requirements.

The problems involved in meeting these criteria have been magnified in recent years. The lack of adequate sewage treatment in some areas and the resulting deterioration of surface waters have made the treatment of these waters much more difficult. These waters now contain chemical compounds which were not present in the past. Some of these chemicals will impart objectionable tastes and odors to the water and some resist removal by conventional treatment processes. For example, synthetic detergents as used in the household cannot be completely removed by the water treatment processes normally used. Therefore the treated water may have a tendency to foam when agitated, depending upon the concentration of the detergents.

As the population of this country continues to grow and increase in density, the problems of water treatment will become greater. The available good quality water resources will continue to be depleted, and water reuse will need to be practiced to a greater degree than at present. Many of the techniques needed for the production of satisfactory water are known but their application may be costly. In other cases, such as the problems of synthetic organic chemicals, the techniques for removal must be developed by research in the near future.

Traditional Design and Construction Practices

In general, there are eight well-known combinations of processes used for water purification:

1. Prolonged storage.
2. Filtration through slow sand filters.
3. Coagulation and filtration through rapid sand filters.
4. Water softening.
5. Iron and manganese removal.
6. Combined water softening and iron removal, coagulation, and filtration through rapid sand filters.
7. Disinfection.
8. Fluoridation.

In addition to these, there are a number of special treatment processes and modifications. Very often it is necessary that a combination of treatments be used in order to obtain the desired results.

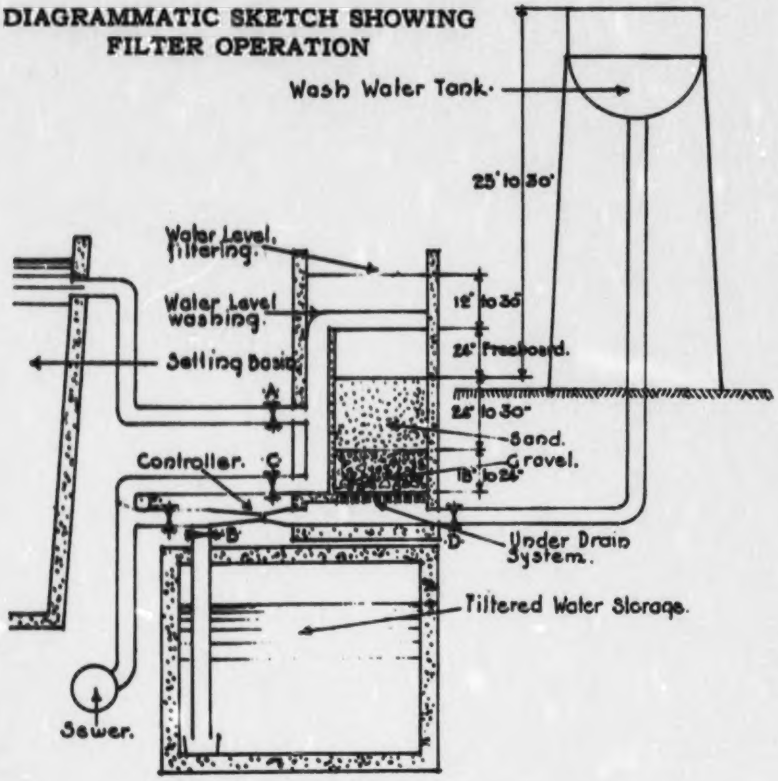
Prolonged storage involves storage in basins or reservoirs for an extended period of time, thereby affording an opportunity for subsidence of silt and clay, reduction in color, and the death of bacteria. Considerable time is required for these results to be accomplished by storage alone, and even then bacteria and finely divided particles of clay are not entirely removed. The size of the basins or reservoirs required normally makes this method very expensive. The tendency toward stagnation and the multiplication of low forms of animal and vegetable life often makes this type of treatment undesirable. Even though many days of storage are provided, additional treatment usually is required to insure a satisfactory product.

Slow sand filters are beds of sand 30 to 40 inches deep, contained in concrete basins, each about one acre in area. Slow sand filters are used extensively abroad, but few have been built in the United States since the development of the rapid sand filter around 1890. The slow sand filter is adapted to water having a turbidity not exceeding about 30 ppm and of low color. The chief disadvantages of slow sand filters are:

1. The large area required.
2. Their successful operation is limited to clear water with low color.
3. The first cost is relatively high.

Rapid sand filters - To obtain a high rate of filtration through sand filters, it is usually necessary to treat the water ahead of the filters. This preparatory or primary treatment may consist of aeration, coagulation, and sedimentation. The gravity type rapid sand filter may be described as a concrete box with a strainer system near the bottom, which is covered with 18 to 24 inches of graded gravel, topped by 24 to 30 inches of filter sand (see Figure No. 1). The primary treated water filters down through the sand and gravel. When the filter becomes clogged, it is washed by forcing filtered water upward through the strainer system, gravel, and sand. The sand is lifted and well agitated in the rising stream of clean water. All the finely divided and suspended matter is carried away in the wash water and wasted. After the filter is washed,

DIAGRAMMATIC SKETCH SHOWING FILTER OPERATION



How Filter Operates

1. Open valve A. (This allows water from settling basin to flow to filter.)
2. Open valve B. (This allows water to flow through filter to filtered water storage. During filter operation all other valves are closed.)

How Filter Is Washed

1. Close valve A.
2. Close valve B when water in filter filters down to top of overflow.
3. Open valves C and D. (This allows water from wash water tank to flow up through the gravel and sand, loosening up the sand and washing the accumulated dirt from the surface of the sand, out of the filter, and into the sewer.)

How to Filter to Waste

1. Open valves A and E. All other valves closed. Water is sometimes filtered to waste for a few minutes after filter has been washed in order to condition the filter before it is put into service.

(From Water Supply and Treatment, C. P. Hoover, 1951
Published by National Lime Association)

Figure No. 1

for a short period, the filter normally is ready to be placed back into service. Despite the considerable improvement over slow sand filters, the rapid sand filter continues to occupy a considerable portion of the total treatment plant space and is costly. Attempts have been made through research to find less costly substitutes and to increase the capacity of existing units.

Other methods of filtration which may be used include pressure filters and diatomite filters. In pressure filters the water is forced through sand in a closed vessel. Diatomite filters utilize a filter aid, diatomaceous earth, as deposited on a porous surface as the filtering media.

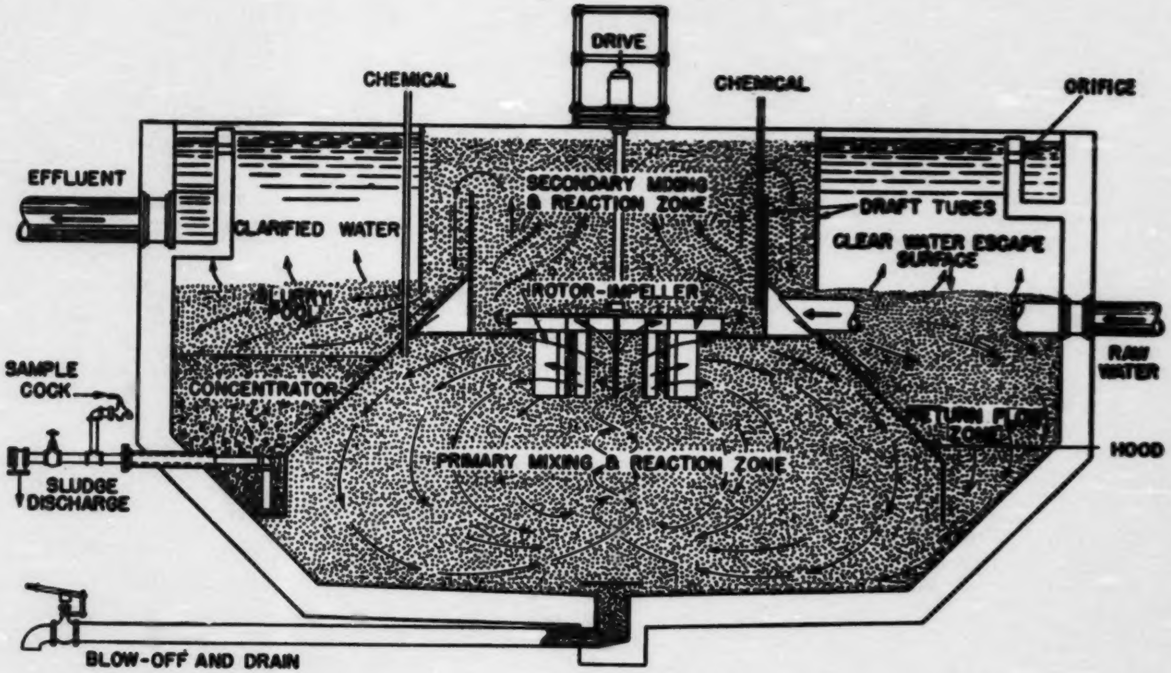
Aeration is not necessary for all waters. Aeration may remove offensive tastes and odors from surface supplies if they are due to dissolved gases. If, however, the tastes and odors are due to dissolved organic matter, aeration will not be effective. Ground water supplies often contain carbon dioxide, and sometimes hydrogen sulphide, iron, and manganese. Aeration reduces the carbon dioxide and hydrogen sulphide, and will normally oxidize the iron, thereby causing it to precipitate so that it can be readily removed by filtration. Large amounts of manganese are not as easily removed as iron, since aeration and filtration alone are usually not adequate. However, the addition of lime will allow the manganese to be precipitated. Some of the ways of accomplishing aeration are by allowing the water to flow over cascades or steps, by spraying from nozzles, by trickling through trays filled with coke, or by wood slot and forced draft aerators.

The primary object of coagulation is the removal of turbidity, color and suspended materials, colloidal in nature and so finely divided that they are not removable by filtration. Coagulation is also responsible for the removal of significant amounts of bacteria and organic matter. Alum and iron salts are the chemicals generally used. The chemical dosages for optimum floc formation vary widely for different waters and must be experimentally determined. The handling, storage, feeding, and rapid solution of the chemicals have been some of the problems associated with this process. After the chemicals are fed into the water in the predetermined amounts, they must be thoroughly and quickly mixed with the water in order to obtain full effectiveness. This "flash" mixing may be effected by passing the water through a specially baffled basin, by pumping, or by mechanical mixers. The last two methods permit agitation to any desired degree, and may allow the use of less chemicals because of the thorough mixing. They also require less space. After the rapid or "flash" mixing, it is desirable to aid the formation of the floc by giving the water a continual slow rolling motion. This is known as flocculation and generally is effected by using revolving paddles or impellers. The velocity of agitation should be kept under 2 feet per second, in order to prevent excessive turbulence and the resulting floc destruction.

Sedimentation - Horizontal flow basins for either plain sedimentation or removal of coagulation floc should provide for very slow and uniform movement from the inlet to the outlet, without short-circuiting so far as possible, and for a retention period of 4 hours or longer. These basins are constructed either circular, square, or rectangular in plan and normally are about 12 feet in depth. It is advantageous to provide mechanical devices for the continuous or frequent removal of the sludge. There are two general types of sludge collectors used. In one, the mechanism revolves very slowly about a vertical central shaft, carrying scrapers which slowly push the sludge toward a central well from which it may be removed by pumping or gravity. In the other type of collector, the scrapers are pulled in a straight line through a rectangular tank by endless chains, thereby pushing the sludge to a well near the inlet end from which it may be removed. With both types the movement is slow in order to avoid interference with the settling process.

Vertical or up-flow settling tanks, frequently called sludge blanket or solids contact units, also may be utilized (see Figure No. 2). In this type of unit the coagulated water is passed downward to the bottom of the tank, in a mixing zone, where the floc is produced, then up through a sludge blanket of previously accumulated floc to an overflow at the top. In passing through the sludge blanket, the heavier floc settles to the bottom by gravity and the remaining floc is removed by the filtering. In most designs, this removal is further induced by gradual deceleration of the upward flowing water. In order to maintain the sludge blanket at the optimum depth and consistency, a portion of the sludge is continuously withdrawn after using either an internal or external concentrator.

Softening is usually accomplished by one of two processes. In the first, lime and soda ash are added to the water. These chemicals change the bicarbonates and sulfates of calcium and magnesium (hardness) from their soluble to an insoluble form in order that they may be removed



Up- Flow Settling Unit as Manufactured by Infilco, Incorporated

Figure No. 2

by sedimentation and filtration. The lime-soda process may leave the water supersaturated with normal carbonates of calcium and magnesium, therefore, subsequent stabilization may be necessary. Furthermore, magnesium removal poses a problem since it is precipitated as a hydroxide and requires caustic alkalinity to be present during the softening reaction. Stabilization of supersaturated calcium carbonate may be effected by recarbonation, the addition of acid, the use of sequestering polyphosphates, or by contact beds. Recarbonation using carbon dioxide or split treatment may be required where magnesium removal is necessary. Up-flow units may be an effective softening and stabilizing device when high concentrations of calcium carbonate can be maintained in the sludge blanket.

The amounts of sludge produced from lime treatment of water often offer a real problem of disposal. Methods currently used include discharge to water courses (which may create a water pollution problem), to sludge beds or lagoons, or into sewers and sewage treatment plants (requiring that the sludge handling capacity be increased). The sludge can also be calcined to recover calcium oxide, but this is not economical in plants producing less than 5 to 10 tons of sludge a day.

In the second method of softening, the water usually is passed through a bed of a basic exchange material such as sodium zeolite. An ion exchange takes place between the sodium, which does not cause hardness, and the calcium and magnesium. At intervals the bed will require regeneration by passing brine solution through it. In this method the total solids in the water remain virtually unchanged.

Iron and manganese removal may be accomplished by either oxidation or by zeolite treatment. Oxidation may be effected by aeration, as described above, or by the use of potassium permanganate or chlorine. When using potassium permanganate or chlorine, the chemical is added to the water prior to coagulation, sedimentation, and filtration. Depending upon the amount of impurities present in the water, sedimentation may or may not be included. Zeolites will remove soluble iron and manganese simultaneously with hardness, as will the lime softening process. Special zeolites for iron and manganese removal can also be used. Sodium or potassium permanganate is used for the periodic regeneration.

In some applications, particularly in industry, a demineralized water may be required. This objective can be effected by the use of anion-cation exchange units.

Disinfection - The water purification methods discussed above cannot be relied upon to remove bacterial contamination to an acceptable degree, much less assure the absence of infectious agents. The application of chlorine is nearly always the method chosen to provide the necessary safeguards. Chlorination to effect disinfection within a reasonable contact time must be a carefully controlled procedure. It requires precise feeding mechanisms, careful instrumentation and a contact period to be effective.

By the use of sufficient quantities of chlorine to fully oxidize all organic and oxidizable inorganic material, effective taste and odor removal often can be accomplished. This process, known as "breakpoint" chlorination, produces a free chlorine residual. Where this residual produces an objectionable taste, a declorinating agent such as sulfur dioxide can be used. Another alternative is to add small amounts of ammonia to change the chlorine residual to the more stable chloramine form which has slower bacteriocidal properties.

Fluoridation - Maintaining a level of fluorides in drinking water between 1.0 and 1.5 mg/l to reduce dental caries in the consuming public is accepted practice for many municipalities. Controlled fluoridation is not difficult in most cases, particularly in surface supplies or where multiple points of distribution of water are not encountered. Specialized equipment which permits careful control over residual fluorides is employed. Communities whose water supply contains excessive natural fluorides have removed it by treatment or changed to a more acceptable supply.

New Materials, Equipment, and Designs and the New Application of Older Materials, Equipment and Designs During the Past Ten Years

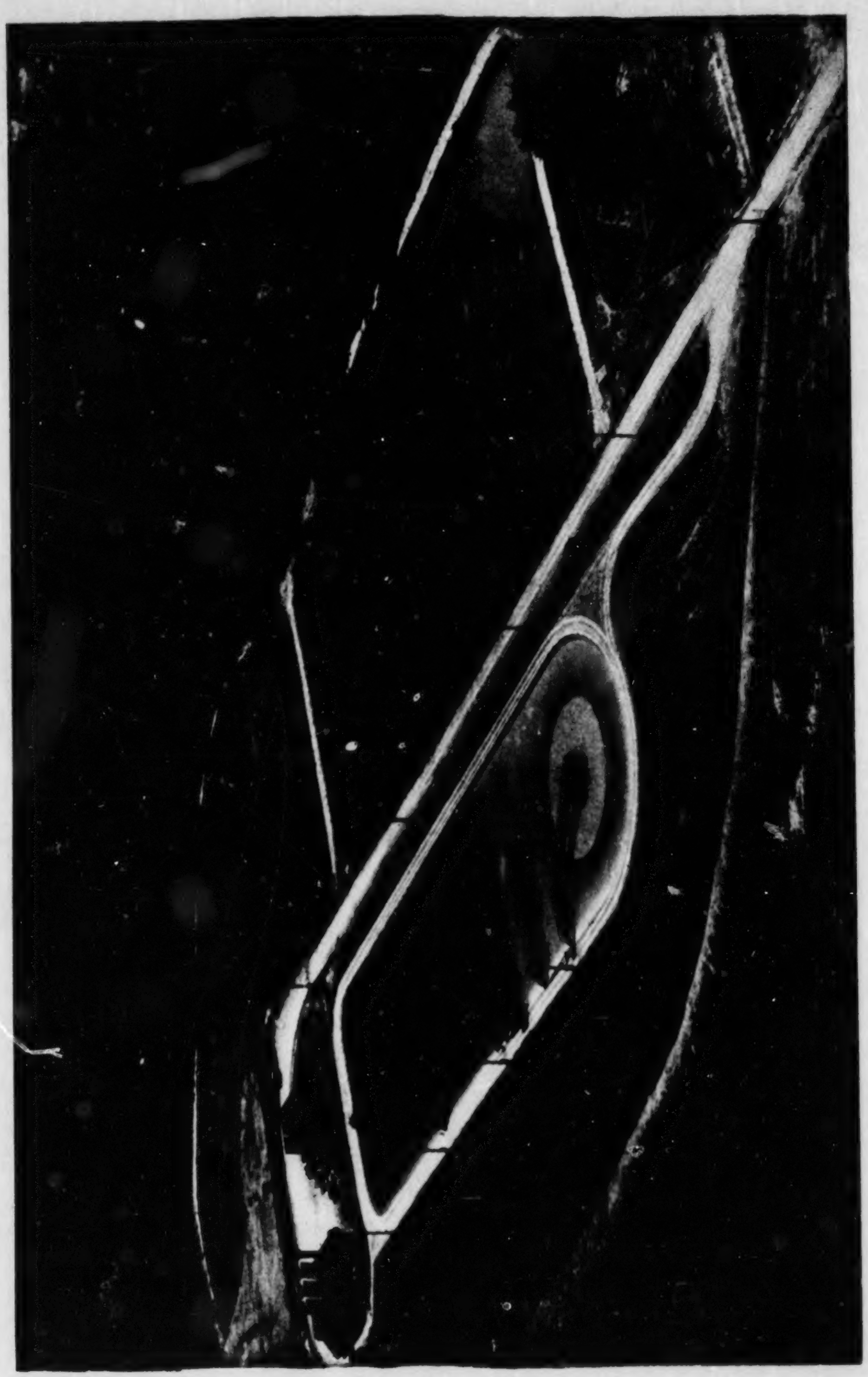
Several new developments as well as adjustments in the conventional methods of treatment to meet changing conditions have taken place in recent years in the water treatment field. For instance, in the last category, new plant designs for treating lower Missouri River water no longer include presedimentation facilities. It has been found that since the multipurpose dams have been constructed upstream, the turbidity of the water has been reduced to the point where these units are no longer justified. At the same time many plants have found they have had to use increasing quantities of activated carbon in order to control tastes and odors.

To a limited degree, micro-strainers with woven stainless steel wire fabrics have been used in water plants. Their applications include: (a) as the sole straining process, (b) as primary straining ahead of either rapid or slow sand filters, and (c) for the treatment of industrial water supplies.

There have been numerous innovations in the design of gravity rapid sand filter plants. There have been a number of plants built which utilize pumps in place of rate-of-flow controllers for filter control. The pump with its motor control and check valve constitute the entire filter effluent control system. These same pumps can also serve as high service pumps. In small plants, in particular, this arrangement will save capital costs. It will also allow clear well storage to be placed above ground, thereby eliminating a potential pollution hazard and possibly affecting additional economies.

The St. Louis County Water Company has many unique features and departures from convention in its South Plant (see Figure No. 3). Among the unusual features are:

1. A remote-operated river intake, consisting of submersible pumps, valves, and limit switches,
2. A sloping, earth embankment purification basin, containing all treatment process units including filtration,
3. Flocculating drives which do not require a dry well,
4. A submerged filter within the treatment basin,
5. A filter without clear well or rate-of-flow controller,
6. Submerged, hydraulically operated butterfly filter valves and piping, which eliminate the need for the conventional pipe gallery, and
7. A pitot tube and pneumatic controller for filter wash water.



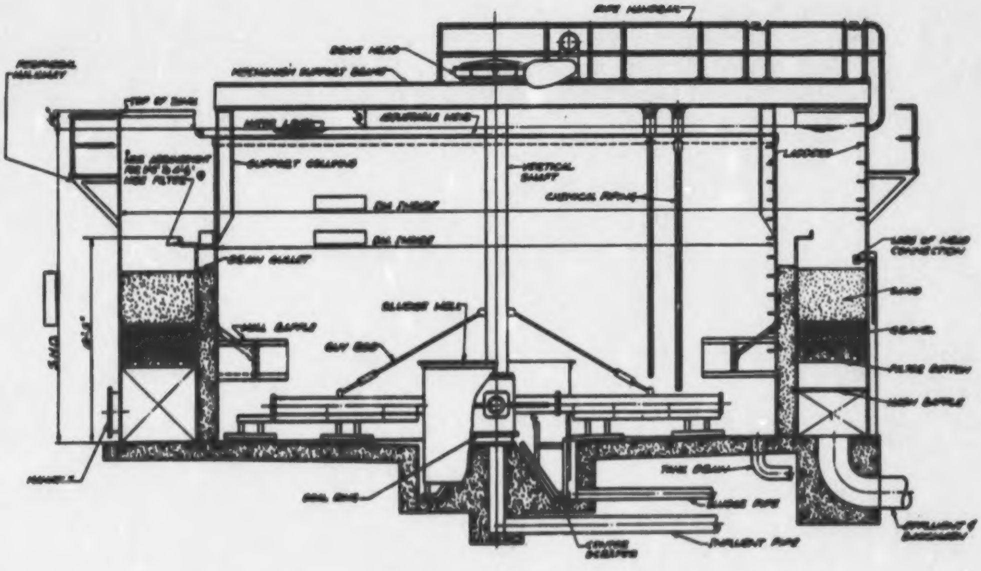
The South Plant of the St. Louis County Water Company

Figure No. 3

At the United States Atomic Energy Commission installation in Hanford, Washington, a revolutionary process of water treatment was developed. Known as the Micro-Floc Process, it basically involves the production of a filterable, rather than a settleable floc, and the use of much higher filter rates than with conventional design. Instruments are used to quickly determine the minimum amount of inorganic coagulants necessary to insure that all of the turbidity in the raw water is converted to a filterable form. A polyelectrolyte is added directly to the water as it enters the filter, thereby increasing the filter's ability to retain turbidity particles. The filter which is constructed of fine anthracite coal aggregate on top of a layer of sand is designed so that the entire bed functions, instead of the top two or three inches as in a conventional filter. This is accomplished by using extreme care in the selection, gradation, and placing of the media. It is also claimed that much longer filter runs than normal may be obtained with these filters.

There have also been developed for use in water treatment plants, equipment for basins which will carry out more than one process. These include coagulation and sedimentation; coagulation, sedimentation and filtration; and softening and filtration (see Figure No. 4). There have also been developed several designs for prefabricated package plants that include means for carrying out all of the necessary stages of water treatment.

In the present day water treatment plant, the sand filter represents the greatest share of the capital and operating costs yet it does the least work. Research initiated by the Public Health Service is seeking new, more effective processes that would eliminate the filter.



SECTIONAL ELEVATION

**Unit Containing Coagulation, Sedimentation and Filtration Facilities
As Manufactured by Dorr-Oliver, Incorporated**

Figure No. 4

Note: Since the design and construction of water treatment plants must address itself to the problems of water treatment and plant operation and maintenance, much of the above applies also to the following subject which deals with plant operation and maintenance.

WATER TREATMENT PLANT OPERATION AND MAINTENANCE

General

The problem of treatment facing the municipal water supply industry is that of producing a high quality product being increasingly demanded by its consumers, from a resource which is continually being degraded in quality. The immediate solution of this problem depends upon improvement of water treatment processes and the equipment and materials used; the real solution lies in more effective pollution control.

Water is the universal solvent and even though it has a way of purging itself of substances, some of the new chemical compounds being developed by man persistently remain in water. These facts could not have been discovered without the aid of new analytical techniques but instead of providing answers, they raise more questions regarding our understanding of water, and our ability to purify it and make it safe to use.

Providing the desired water quality involves, among other things, the methods of controlling, removing, or destroying objectionable organic and inorganic solutes or colloids, and pathogenic or other undesirable organisms, and financing the undertaking. Improvements are needed for controlling motile organisms able to penetrate water treatment plants and infect distribution systems. Also needed is more knowledge regarding the fundamentals of water purification processes in order, for example, to improve the effectiveness of coagulation and filtration. The use of new chemicals needs exploring, one example being the possibility of finding strong chemical oxidants to destroy objectionable, persistant organic compounds. There is a need for water quality standards which not only define waters that are safe but are demanded, and will be financed by the consumers.

The Problems Involved

The provision of safe and good quality water is a problem of considerable magnitude. No other local industry produces as many tons of finished, manufactured product as the local water utility. Today, municipal water utilities process an average of 75 million tons of water each day, with treatment ranging from simple chlorination to complex filtration processes. The chemical requirements for this processing is measured in thousands of tons each day. Even though the quantities are large in their aggregate, the rates of use are measured in parts per million or pounds of chemical per million pounds of water.

On the average, a community water treatment plant processes over 1/2 ton of water each day for every person served. All of this water must be wholesome and safe to drink, even though the average person drinks little more than 1/2 gallon each day.

There are over 9,900 separate systems treating water for towns and cities in the United States in addition to the 7,900 which do not treat their supply. Even though there is a wide range in skills required, each plant must have at least one competent person in charge. Water treatment requires scientific supervision and one of the problems facing the water works industry in this area is the recruitment and training of qualified personnel. Since public water supply is usually a local undertaking adds to this problem because the number of qualified personnel needed is much larger than if centralized water supply systems served many communities.

New Chemical Contaminants - Many references have been made to the growing complexity of the water treatment problem. Hundreds of new chemical substances are being marketed annually, among them being detergents, pesticides, and industrial chemicals of a wide variety. After use, many of these compounds find their way into watercourses where it is hoped no toxic effect results to either humans, aquatic life, or animals. Since conventional water treatment processes do not remove many of these chemicals or only partially, there is reason for concern. This concern is rising as the concentration of these new chemicals at water supply intakes is increasing each year.

The newly adopted (April 5, 1962) Public Health Service Drinking Water Standards prescribe limits for the concentration of some types of synthetic chemicals but it was not deemed feasible at the time of adoption to include limits for the many chemicals with a toxic potential that may get into water supplies. Specific limits were not set for the more common chlorinated hydrocarbons and organophosphate insecticides but it was recognized that pollution of water supplies with such contaminants can become significant. Simple and practical analytical methods to identify and measure these latter organic materials in water are not yet available, although several can be measured with difficulty at concentrations as low as a fraction of a part per billion.

Under drought conditions, detergents have been found in streams used for public water supply in concentrations sufficiently high to cause foaming, taste and odor, and to cause difficulty with coagulation. These compounds have also been found frequently in ground water supplies. Activated carbon in high dosages will remove detergents but this process is not presently being used in public water supply practice. Removal of detergents by an ion-exchange resin has been demonstrated in the laboratory but it has not yet been shown to be practical for use in a municipal water treatment plant. ABS, the most common detergent chemical, has not been concentrated enough in most streams used for water supply to cause difficulty with coagulation but the phosphate "builders" used in household detergents have caused such interference.

The presence of radioactivity in higher than background concentrations in both ground and surface waters has become a matter of concern to the water works industry. Radioactive fallout, the growing use of radioactive isotopes, and the use of radioactive materials for power production present opportunities for contamination of water supply sources. Instruments and methods of analysis for radioactivity are available but not widely used, and a number of problems connected with radioactivity remain to be solved.

Tastes and Odors - Activated carbon is most generally used for controlling tastes and odors. Chlorine dioxide, potassium permanganate and break-point chlorination are also used. In most situations, these treatment methods have been effective in removing the tastes and odors usually encountered. However, in an increasing number of instances, threshold odors and new chemical contaminant problems are being reported where such treatment has not been effective, or is expensive.

As the streams and rivers become more highly regulated, problems of tastes and odors are expected to increase. This will require the development of much more effective control measures and removal processes than are presently available.

Coagulation Problems - Coagulation of colloidal turbidity with alum or an iron coagulant is an empirical process and difficulties are often encountered in water treatment. Fundamental studies are needed to develop a science of coagulation in water treatment; also in the development of new coagulant chemicals and processes.

Chemical Handling, Storage and Feeding - Many of the advances in the industrial handling of materials have not found their way into the water works industry. Newer plants take advantage of bulk delivery by either truck or railroad but in many older plants chemicals are handled bag by bag, without pallets, lift-trucks, etc. Alum in liquid form has become increasingly common and used in this form greatly simplifies unloading, storage and accuracy of feed. Troubles have been experienced with crystallization of the alum at lower temperatures and when it contains potassium aluminum sulfate. Dust difficulties are common with powdered activated carbon and hydrated lime. Hydrated lime slurries are difficult to handle because of their tendency to plug lines.

Pipe Lines, Meters, Valves at Treatment Plant - Plastic pipe is now commonly used for conveying solutions of water treatment chemicals and difficulties with breaking of the lines, leaky joints and bending are common. Meters and metering pumps for control of treatment chemical solutions are available, but lack flexibility and a wide enough range to meet the load requirements of a treatment plant. Valves used in treatment plants are subject to corrosion and graphitic deterioration.

Traditional Practices

Source Protection - The time-tried procedures of using the least polluted sources available and protecting the source from further pollution remains an accepted sanitary engineering procedure in the water works field. Source protection varies from the elaborate watershed policing arrangements of cities like Boston, New York, and Seattle to "clean-up" programs of severly polluted streams like the Ohio, Delaware, and Potomac. The "Clean Streams Program of Pennsylvania" is an example of the benefits of pollution control which accrue to water supply.

Treatment Practices - The water treatment plant operator has found it necessary, because of increasing pollution, to improve the efficacy of the water treatment procedures with which he has to work. These differ little from those in use 50 years ago except for slight modifications.

1. Coagulation and Sedimentation - Coagulation is accomplished mostly by use of alum compounds although a significant amount of other chemical coagulants are used, such as iron salts and lime. By improvements in flocculation equipment and settling efficiency, plant operators are able to produce water with turbidity of 5 or less before filtration, whereas in former years, they were limited to reductions to 20 to 35. Improved coagulation and better sedimentation, together with effective

pre-chlorination, have eliminated in many plants the need for periodical filter cleanings often carried out annually at some plants. Coagulation difficulties remain a problem but with the introduction of activated silica and the new coagulant aids, these difficulties can be made less troublesome.

2. Filtration - The rapid sand filter is called upon to do only a very small percentage of the total removal work of a water purification plant. Where some years ago, the filters removed 90% of the bacteria and 20-30 units of turbidity, in present day practice prechlorination decreases the filter load (bacteriological) to almost zero, and the turbidity removal is 25-30% of that formerly required of these units. Filtration rates remain at the original 2 gpm/sq. ft. loading although many new plants are designed hydraulically to exceed this rate by 50%. Rapid sand filters, almost identical with those originally installed, now produce water with turbidity of less than one and length of filter runs between washings has been extended to 50 to 100 or more hours. Previously a 24-hour filter run was often a goal to be strived for.

Filter washing has seen little change except for increased rise rates and an awareness that 50% sand expansion is necessary for proper cleaning. Surface filter wash systems are common. Wash control is passing from manually controlled hydraulic valves to push-button initiated, timed-sequence automatic washing. Filter wash water and sedimentation basin sludges cannot now, in some States, be returned freely to the rivers from which they come.

3. Disinfection - Chlorine is still the principle chemical used for disinfection; however, many plants now rely on pre-chlorination as well as post-chlorination. This introduces a definite, additional factor of safety for assuring adequate disinfection.

Laboratory control procedures have shown little change in the past 25 years, but there has been some equipment change. Electrometric pH determinations are now the rule rather than colorometric procedures, and colorimeters, and photometers are rapidly replacing visual colormetic and turbidity determinations. The membrane filter technique of bacteriological analysis is rather slowly becoming standard practice.

New Materials, Equipment, and Designs and New Applications of Older Materials and Equipment

While traditional practices in water treatment have not changed greatly, many procedure modifications and improvements have been made in recent years.

Clarification

1. New Chemical Coagulants and Aids - Some compounds of a class of chemical materials called polyelectrolytes have been found to be effective coagulant aids. Spectacular results have in some cases achieved through the use of extremely low concentrations of these materials. These compounds are synthetic polymers of high molecular weight, analogous in general properties to naturally occurring polymers carrying electric charges or ionizable sites.

These naturally occurring polymers are called biocolloids, among which are starch and starch derivatives, cellulose compounds, and polysaccharide gums. Three general classes of polyelectrolytes are available: (a) negatively charged compounds, called anionic polyelectrolytes; (b) positively charged compounds, called cationic, and (c) compounds having both charges, called polyampholytes. Approximately 29 manufactures' products have been approved for use as coagulants aids (with restrictions) for public water supply treatment.

2. Coagulant Control with Zeta Potential - Chemists and operators have long searched for a control test or signal that would indicate proper coagulation of a water being treated for clarification and filtration. Zeta potential is one of the potential values associated with colloids in suspension in a solution. It is reported that the magnitude of the Zeta potential can be rapidly and accurately determined. Since rapid coagulation of a colloid takes place shortly before the Zeta potential has been completely neutralized, it is hoped these values can be used for determining when coagulation dosages are correct. However, considerable work remains to be done before a reliable procedure can be developed and incorporated in water works practice.

3. Chemical Coagulants - While liquid alum has been available for a number of years, and has been used quite extensively by the paper industry, little or no alum in this form was used in the

water works industry before approximately 1955. Since that time numerous small alum manufacturing plants have been installed at various convenient locations throughout the country. Stored in lead-lined or rubber-lined tanks (steel, concrete, wood), the use of the liquid material has resulted in lower costs, elimination of dust, savings in unloading costs and better dosage regulation. A new form of dry alum designed to eliminate dust and feed more easily is said to have been recently placed upon the market. Also, alum from coal mining wastes will soon be available.

4. Increased Filter Rates - There is a gradual tendency toward somewhat higher filtration rates in conventional rapid sand filters. The Torresdale plant of the Philadelphia City Water Department operates under peak demand conditions at 3 gpm/sq. ft. as do all filters designed for the American Water Works Company system in the past decade.

5. Automatic Filters - Many new filter installations are of the semi-automatic, push-button type in which the operator initiates the wash cycle but from there on, the filter washing operation is automatic. Automation has also been extended to iron removal plants in some locations, and to resin exchange softening plants where hardness of the raw water is reasonably constant.

Removal of Objectionable Chemical Substances

1. Softening - Lime-soda softening plants have shown little change in a number of years. However, there has been an advance in the knowledge of softening to gain greater efficiency and a

trend in large softening plants to recalcining for recovery of lime.

2. New Ion-Exchange Resins - The introduction of high capacity, styrene base resins has made possible smaller base-exchange softening plants, because of the much greater exchange capacity of these resins (16 to 45 killograms per cubic feet) and the higher throughput rates possible without deterioration of the effluent water. Many such softening systems operate at 10 gpm/sq. ft. and even higher rates are possible with some loss of capacity.

3. Iron and Manganese Removal - The new coagulation-filtration process developed at Hanford shows promise of rates up to twice the normal for iron removal plants. Manganese removal with potassium permanganate is efficient and practical. In a moderately low hardness well water, high in manganese (up to 9 ppm) an ion-exchange plant for manganese removal proved more economical in first cost and in operation than a conventional type plant, because of ease of automation and control. Potassium permanganate has also been used recently in less than normal dosages in zeolite beds, a new development in iron and manganese removal processes.

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DESIGN AND CONSTRUCTION OF SEWAGE AND INDUSTRIAL WASTE COLLECTION SYSTEMS

General

All communities produce waterborne wastes and are affected by the runoff of precipitation. Sewers perform the function of collecting waterborne wastes of domestic, commercial and industrial origin, and storm waters, for conveyance to points of discharge or disposal, and are necessary to the health and welfare of the community.

Modern practice is to design and construct two separate sewer systems -- sanitary and storm water. This report is primarily concerned with sanitary sewer systems since it is the wastes in these sewers which can adversely affect public health and which contribute most to water pollution. In the design of sanitary sewers, the engineer must develop estimates of the quantity of flow to be conveyed at some time in the future, since these facilities are not easily enlarged.

The Problems Involved

Part of the problem in estimating flow is to make allowance for: (1) ground water infiltration, since sewer joints are never made perfectly watertight; (2) roof and foundation drainage, because there are always connections of this sort to sanitary sewer systems even though such connections may be illegal; and (3) peak flows, since water usage and consequently sewage flow is not constant throughout the day, week, or even year. Exclusion of ground water, roof and foundation drainage from sanitary sewer systems is most important for economic and functional reasons. Excessive flows require increased investment in both sewers and sewage treatment facilities.

In planning the system, the engineer must strive to obtain as economical a plan as he can. Gravity conduits are utilized wherever the topography permits. However, where gravity flow cannot be achieved, pumping equipment is necessary in order to deliver the wastes to the point of treatment and disposal. Furthermore, the engineer must design a sewer system in such a manner that the velocities within the conduits will be sufficient to keep the sewage solids in suspension. The layout of the system requires a careful study of the tributary area in order that all properties are served in the most effective and economical manner.

The preparation of construction drawings and specifications and the construction of the facilities pose further problems. Among the most important of these is the selection of materials to be used. The following factors must be considered:

1. Flow characteristics - friction coefficient.
2. Life expectancy and use experience.
3. Resistance to scour.
4. Resistance to corrosion and to attack from acids, alkalines, gases, solvents, etc.
5. Ease of handling and installation.
6. Strength to carry structural loads.
7. Type of joint (watertightness and ease of assembly).
8. Availability and ease of installation of fittings and connections.
9. Availability in sizes required.
10. Cost of materials, handling, and installation.

The methods of construction available to the contractor as well as the conditions which may be encountered must also be considered.

Traditional Design and Construction Practice

The design of a sanitary sewer system must take into account the problems enumerated above and insofar as possible, resolve them. The size, slope, and depth of the sewer and the materials of its construction must be determined. Attention must also be given to obtaining proper design of appurtenances such as manholes, junction chambers, and other structures to minimize turbulence and head loss, and to prevent deposition of sewage solids.

It is obvious that care should be exercised in providing proper pipe and conduit sizes, in the selection of materials, and in the details necessary to achieve soundness of construction. Vitrified clay, concrete, asbestos-cement, cast iron, steel, and brick masonry are the materials that normally have been used for sewer construction. Not all of these materials can be used under all conditions.

Joints must be designed and constructed to be watertight, resistant to root penetration, resistant to corrosion, have a reasonable degree of flexibility, and be durable.

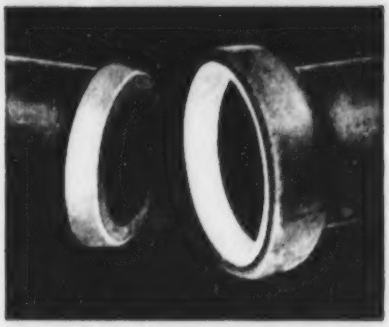
The number and location of pumping stations required must be selected with care. This decision may quite possibly be based upon the maximum desirable depth of sewer lines below the ground surface. This limitation may be determined by soil conditions, rock, or ground water levels. In any case, the construction, operation, and maintenance costs of a pumping station must be weighed against the costs of construction and maintenance of sewer lines.

Sewage pumping stations serving more than 50 homes are normally of the wet well-dry well type of construction. The sewage enters the wet well, sometimes through a bar screen, where 5 to 10 minutes storage capacity is provided. The pumps, generally of the non-clog centrifugal type, are installed in the dry well with all the necessary piping, valves, and controls. The motors may be close-coupled to the pumps or raised out of the way of any possible flooding by the use of extended shafts. Normal practice is to install more than one pumping unit with the capacity of each such that, if any one pump is out of operation, capacity remains to handle peak flows.

Use of New Materials, Equipment, and Designs and New Application of Older Materials, Equipment and Designs

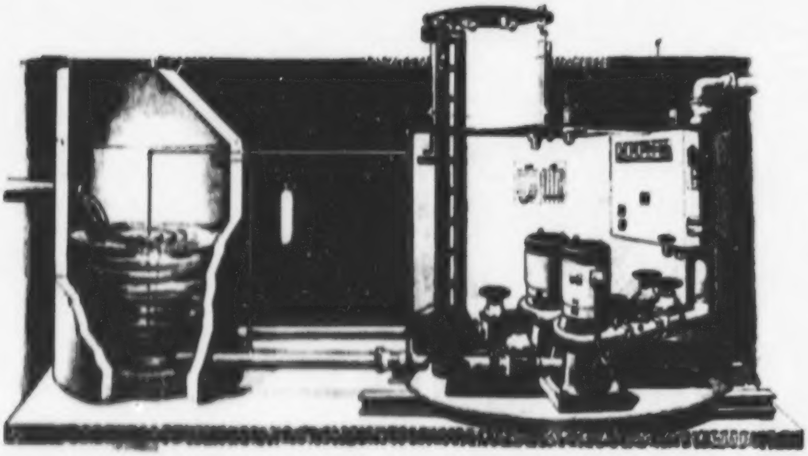
In recent years there have been several new developments with respect to pipe sewers. Most of these have been concerned with the improvement of pipe joints to prevent ground water infiltration. Some of the materials for this purpose have been in common use for other purposes for many years. In addition there have been several new materials introduced in recent years for use in sewer pipe, but these have been primarily for smaller lines and house connections, or for use under abnormal conditions of one sort or another.

Factory-made joints using resilient materials for vitrified clay pipe can be grouped into three basic material combinations: (1) those joints in which the same resilient material is used on both bell and spigot ends with one varying in hardness from the other (see Figure No. 5), (2) those joints using different types of resilient materials in the bell and spigot ends, and (3) those joints which rely upon gasket or compression



Polyvinyl Chloride Joint for Vitrified Clay Pipe
As Manufactured by American Vitrified Products Company

Figure No. 5



Smith and Loveless factory-built duplex pumping station, designed for capacities from 100 gpm to 4,500 gpm per pump with two or more pumps installed complete with all accessories.

Figure No. 6

ring. The last type of joint is also used with concrete pipe. The resilient materials used include plasticized resins of polyvinyl chloride, plastisol, a polyester plastic, and a phenolic plastic. Gaskets or compression rings are normally made of rubber or neoprene.

The new pipe materials which have been developed and are available in sizes generally less than 8 to 12 inches in diameter include plastic, polyvinyl chloride, Fiberglas reinforced epoxy resin, polyethylene and styrene. Bituminized-fiber pipe has been used for house connections and a limited number of other applications. Many of these new materials were developed to offset such problems as corrosion, watertightness, and resistance to chemical attack.

It has often been common practice to build concrete sewers of the larger diameter in place. These sewers have on occasion been lined with vitrified clay, bituminous, or plastic liner plates for corrosion resistance. In recent years a number of new machines have been developed for casting concrete sewers in place by the slip-form method. One such machine operates in an excavated trench and consists primarily of a traveling form with facilities for distributing and vibrating the concrete as it is poured. Concrete is supplied to the machine hopper by transit mixers. Equipment is available to construct pipe 24 to 60 inches in diameter at a maximum depth of 16 feet.

Another machine, operating in a trench excavated to the outside diameter of the pipe to be laid, is propelled at the desired speed, laying the pipe without joints by using aluminum forms supported on the inside with full circle struts. One company provides a machine for building concrete pipe in place, using an inflatable inside form. Pipe with diameters of 12 to 30 inches may be constructed with this machine.

A number of advances have been made in recent years to improve the design of pumping equipment and stations, and to reduce their initial capital cost as well as operating and maintenance costs. Significant reductions in capital costs have been achieved by the use of prefabricated pumping stations. Since in many cases these stations are less costly than on-the-site construction and equipment installation, it has become more economical to use more lift stations with shallower sewer trench cuts, rather than fewer lift stations with deeper cuts.

A number of manufacturers supply these stations which basically consist of a standard pump chamber with an entrance tube (see Figure No. 6). These stations are built of epoxy resin coated steel and are factory assembled to include pumping equipment, an electrical panel, starting equipment and control switches, lights, a ladder, a sump pump, a blower and dehumidifier, cathodic protection, and the necessary pipe and fittings to the outside of the chamber. Optional equipment includes elevators for access to the station. These stations normally are equipped with two pumps, however, it is possible to install three or four. These pumps may be either close-coupled non-clog sewage and trash pumps, or pneumatic ejectors. The unit is delivered to the job site and placed on a prepared concrete slab. After piping and wiring connections are made and earth is backfilled around the unit, it is ready to operate.

Among the newer developments in pumping equipment for sewage and industrial wastes are a "torque-flow" pump which has a recessed impeller mounted out of the path of flow to enable passage of solids the size of the suction pipe, a two-vane open impeller pump which is self-priming to 15-foot lifts, and a number of completely submersible pumps so designed that the entire pump and motor may be submersed in the sewage.

Among the advantages of variable speed pumping are (1) it normally allows a lesser number of pumps to be installed, and (2) the size and depth of the wet well required can be reduced. A variable speed pump control, which is essentially a water rheostat, has been developed. The drive motor (wound rotor type) speed is controlled by the use of a series of stainless steel plate resistors in a two-compartment container. These resistors are wired into a circuit with the wound rotor motor. The submergence of the plates is determined by the volume of sewage to be pumped, and the design of the shape of these resistor plates is such that the pump motor operates at a speed which will cause the pump to discharge at a rate matching the flow.

DESIGN AND CONSTRUCTION OF SEWAGE AND INDUSTRIAL WASTE TREATMENT WORKS

General

With the increasing growth and density of population and continued industrial expansion of our nation, the need for adequate treatment and disposal of sewage and industrial wastes has grown apace. The increased water requirements that go along with this growth and expansion, and the resultant demand for cleaner streams, make waste treatment imperative. Specifically, sewage and waste treatment are required to protect:

Potable and industrial water supplies.

Recreational facilities.

Fish and aquatic life and wildlife.

Agricultural uses.

The aesthetic values of the Nation's rivers and streams.

Sewage treatment works must adequately remove or reduce the solids, bacteria, and chemical constituents of waste waters which interfere with legitimate uses of the receiving streams. The oxygen-demanding constituents of industrial wastes, and those which cause objectionable tastes or odors in water supplies and taint the flesh of fish must be reduced to a satisfactory level. Oils and floating solids in industrial wastes must be reduced to the point where they will not create fire hazards, coat hulls of water craft, injure fish or wildlife or their habitat, or adversely affect public or private recreational development or other legitimate shoreline developments or uses. Also those materials which are toxic to human, fish, aquatic, or wildlife must be eliminated or reduced to known safe limits.

The Problems Involved

In order to achieve these objectives, adequate waste treatment plants must be provided to treat wastes before their discharge to streams. Municipal treatment works must be designed to treat the quantity and quality of wastes to be treated some 20 to 30 years in the future since they normally are built with debt financing. The establishment of this basis of design presents a problem which at best can only be solved by estimation.

The design and construction of sewage and industrial waste treatment works poses further problems. The primary aim is to select a method of treatment to remove or adequately reduce the objectionable constituents of the waste to protect the uses for which the receiving stream is required, and do this as economically as possible. Selection of methods, equipment, and materials is limited by present knowledge and the number of choices. Current methods of sewage treatment are limited in their ability to remove or adequately reduce the objectionable constituent of the wastes to permit repeated reuse of downstream waters. The equipment and materials must withstand attack by complex wastes and corrosive atmospheres. At the same time, they must perform continuously and efficiently throughout the life of the facility, and provide economies in first cost and in operation and maintenance.

The treatment processes for the disposal of municipal or combinations of municipal and industrial wastes have become somewhat standardized in three phases: (1) Separation of liquid and solids, (2) treatment and disposal of solids, and (3) oxidation of the liquid. The first phase combined with the second is designated as primary treatment; the third phase as secondary treatment. Often the combination of all three phases is known as secondary or complete treatment, the latter being an unfortunate misnomer since even the most efficient wastes processing methods presently known do not remove all oxidizable material, all objectionable dissolved solids or all suspended solids.

The solids-liquid separation may be accomplished by a combination of screening, differential sedimentation, flocculation, and flotation. All of these processes are not necessarily incorporated into any one treatment works. Differential sedimentation may be effected in two stages. The first separates high specific gravity solids, known as grit. The second stage is designed to remove the lighter, more flocculent solids. Normally the grit, aside from being washed, is not subjected to further treatment. Solids removed in the primary sedimentation tanks may be treated in a number of ways prior to disposal. The liquid effluent from primary sedimentation basis is subjected to oxidation measures when further treatment is required before its disposal in the receiving stream.

Traditional Design and Construction Practices

In the treatment of municipal wastes, the liquid-solids separation is normally accomplished by the use of screens and/or shredders, grit collectors, and settling tanks. The screens generally employed in sewage treatment works are racks of bars with clear openings of about 1 inch to 2 inches. These may be either manually or mechanically cleaned. The screenings may then be disposed of by burial or incineration, or they may be ground and returned to the sewage flow. Another means of handling these particles is by comminution, i. e., the reduction of the material to a smaller size by the use of a mechanical cutting or shredding device which functions in the flow.

Since the sand and cinders which are found in municipal sewage are heavier than the organic matter, they will settle faster. Removal may be accomplished by reducing the velocity of the sewage to 1 foot per second. At this velocity the heavier inorganic grit particles will settle, while the lighter organic material will not.

The two most common methods of removing grit are to either pass the sewage through channels in which a velocity very close to 1 foot per second is maintained, or to pass it through basins in which the velocity is always 1 foot per second or less and then wash out from the grit such organic matter as may settle with it. Except in the smallest plants which may have manually cleaned basins of the first type, most grit chambers are mechanically cleaned. The mechanisms commonly in use include chain and bucket scrapers, plow type scrapers, screw conveyors, air-lift pumps, and bucket elevators. The washing devices which may be used sometimes employ air diffusion which would keep the organic matter in suspension, or classifying devices of the reciprocating rake, hydraulic cyclone, or screw conveyor type.

Most of the flocculent suspended solids remaining after screening and grit removal are comparatively easily separated from sewage by plain sedimentation. Settling is a desirable step before discharging the wastes to the secondary treatment or oxidation units, or to a stream which can receive sewage subjected to only primary treatment.

Settling tanks are designed as horizontal or as vertical (up-flow) flow tanks, either rectangular or circular in plan. Normally mechanical equipment of the chain and scraper or plow type is placed in the basins for continuous or intermittent sludge removal so that the deposited solids do not have the opportunity to undergo putrefaction in the basins.

Two-story tanks (imhoff tanks) may be used, generally in smaller plants, in which settling takes part in the upper chamber, and the lower story is used for sludge digestion.

Secondary treatment of municipal wastes invariably involves oxidation, affected by aerobic micro-organisms. The necessary organisms are normally present in sewage and it is merely necessary to create an optimum environment to encourage their domination and multiplication among the microbial life.

Carbohydrates, fats, and proteins present in sewage are food sources for organisms of all types. By oxidizing this organic matter to carbon dioxide, water, nitrates, and ash under controlled conditions, the treated sewage may be discharged to many streams without detrimental effects. Complete oxidation is seldom possible; however, results may be obtained which will allow the stream to purify itself in time. By controlling the environment for the micro-organisms in the treatment plant, types that are selective in their metabolism can be developed to produce optimum results.

In trickling filters, a rock, slag, or other fixed porous medium is provided as a base for organisms to live in a gelatinuous matrix which forms on the media. The sewage normally is applied as a spray by rotating distributors. The filter media is generally 3 to 10 feet deep and is placed on a floor provided with a drainage system. Filters usually are designed and constructed circular in plan with vertical walls. Walls have been built of concrete, stone, brick, clay tile, precast concrete segments, and steel plate. The walls are constructed so that air will be admitted through the drainage system and up through the filter media. Sometimes in colder climates these filters have also been covered to prevent freezing.

The activated sludge process, in contrast to trickling filters, involves biological synthesis of the solids normally suspended in the sewage. In the activated sludge process, it is necessary to keep the biological medium (sludge) in contact with the waste by circulating it and to provide an excess of free air (oxygen) to maintain aerobic conditions. In some systems circulation and aeration are effected simultaneously by introducing compressed air into the basins containing the waste and the sludge. In others both aeration and circulation are accomplished by mechanically stirring the basin contents.

With both trickling filters and the activated sludge process, final settling tanks are necessary to separate the sludge solids and micro-organisms from the oxidized sewage. These settled solids are then either recirculated to the process or returned to the primary settling basins for disposal with the primary sludge.

The solids and oxidizable materials remaining in the treatment plant effluent, by either biological process, must be assimilated by the stream to which the discharge is made. Secondary effluent does not always satisfy the environmental conditions in the stream. Nitrate nitrogen, phosphates and sulfur compounds enrich the nutrient level in the stream and often results in excessive algae and other plant growth which then becomes a problem to be dealt with.

Disposal of the solids from the primary and secondary sedimentation tanks is one of the most troublesome features of waste treatment works. In the digestion process, the sludge (93 to 97 per cent water) usually is digested for a period of 30 to 50 days in a special tank under anaerobic conditions. At the end of that time a degree of organic stability has been attained by the microbiological activity in the tank, and the sludge may be disposed of with little or no odor or nuisance.

Temperature control, about 95 degrees F., is necessary for efficient digestion. Heating facilities have in the past been in the form of heating coils inside the tank; however, present practice is to use external heat exchangers. As fresh solids are pumped to the digesters, the supernatant liquor (water separated from the solids) overflows and is diverted back to the plant to be treated with the raw sewage. Gas from the process, mostly methane, carbon dioxide and small quantities of hydrogen sulfide, is collected and used for heating the digesters. The excess gas may be wasted by burning or in larger plants it is often used to drive gas engines and electric generators. Throughout the process, the presence of explosive mixtures of gas and air is a potential hazard, and the utmost precautions need be taken.

Digestion tanks are normally constructed of concrete, either poured in place or pre-stressed, and are generally circular in plan, but have been square and hexagonal. They may be built with fixed-in-place steel or concrete covers, or with covers which float on the liquid. These covers are usually steel which support either a wood and composition roof, or a roof of insulated metal.

Digested sludge, although stabilized with respect to the organic matter, still contains 85 to 95 per cent moisture. The high water content offers obstacles to disposal methods because on-site methods usually involve total destruction by incineration and off-site methods require transportation. Here again, a liquid-solids separation problem occurs. Where land area is not at a premium and the climate is favorable, spreading on well-drained sand drying beds for drying is commonly used. If the climate factor is unfavorable, it can be offset by enclosing the sand beds in greenhouses. Another method of disposing of digested sludge when ample suitable land is available is by lagooning. Lagoons can provide permanent storage, or they may be periodically cleaned. Where economics or the nuisance potential justifies it, mechanical dewatering has been accomplished with vacuum filters, centrifuges, thickeners, vibrating screens, filter presses, or rotary and flash dryers. The use of these methods usually is appropriate when sludge reclamation and utilization as a soil conditioner is an objective. If there is no market for the dewatered sludge, it must be disposed of as landfill, by deep ocean dumping, or by incineration to ash.

Industrial Wastes - Cooperation between the community and industry in the solution of waste disposal problems has improved a great deal. Nevertheless, there is a need for continuing research, even though there are many industrial waste problems existing today that are amenable to solution. Where the waste problem is one of toxic chemicals, the solution may be one of disposal elsewhere than the public sewers. Many of the organic wastes are becoming more and more conquerable by biological oxidation methods.

The first consideration in handling any industrial waste problem is to commence the solution at the source of the waste. The industrial processes should be thoroughly studied. If possible, a water balance should be undertaken and efforts made to eliminate needless waste, both in raw materials, quantity of water used and waste products. Often, a valuable by-products industry can be established through recovery of waste products and their conversion to usable raw materials or marketable products. Large volumes of relatively unpolluted water should be recirculated or used in process phases where water quality is not critical. It may be possible to discharge these unpolluted wastes without treatment to the receiving stream itself, or to storm sewers or ditches. Highly concentrated waste components, if not salvageable, might more profitably be discharged to other disposal outlets, such as incinerators or dumps, rather than the sewers or a stream. Not at all to be overlooked are the substantial reductions in waste production that can sometimes be affected by changes in unit process and substitution of raw materials having a lower pollution potential.

Volume of flow, uniformity of rate of flow, concentration and character of suspended and dissolved solids, temperature, pH, and carbon to nitrogen ratios are factors which determine treatment methods and need to be studied. Whether or not there are any components of the waste likely to be toxic to biological treatment media is likewise important.

In treating industrial wastes without sewage, it is still possible to utilize mechanical and biological processes familiar in sewage treatment. Screens, particularly of the fine variety, have their application. Sedimentation with or without flocculation, often aided by chemicals, is used for solids removal. Trickling filters and activated sludge processes are readily adaptable to all forms of organic wastes and many that are toxic. Oxidation ponds and spray irrigation may be applicable to organic wastes, and anaerobic digestion has been used for some concentrated organic wastes. Solids treatment and disposal for organic wastes may utilize the methods commonly used in municipal waste treatment. Some processes which are more commonly used in industrial waste treatment plants than sewage treatment plants include flotation, centrifuging, adsorption, and ion exchange.

Biological treatment of industrial wastes with sewage is usually more readily accomplished than without, because sewage furnishes the necessary nitrogen and phosphorus, which are lacking in many wastes. It is quite important to avoid shock loads of either volume or concentration. These can be overcome by the use of holding tanks to equalize these factors and to permit proportionate mixing of the industrial wastes with the sewage. Pretreatment of the wastes is often desirable, taking the form of screening, sedimentation, or chemical precipitation for solids removal; flotation for oil or grease removal; chemical treatment for pH adjustments; or specific treatment for a waste component which cannot be handled in a biological process.

Use of New Materials, Equipment, and Designs and New Applications of Older Materials, Equipment and Designs

Since disposing of the sludge produced in waste treatment works has been one of the major and most costly problems, considerable effort has been made to improve the processes which have been used, as well as to develop new methods. Much of this work has been concentrated on the digestion and vacuum filtration processes.

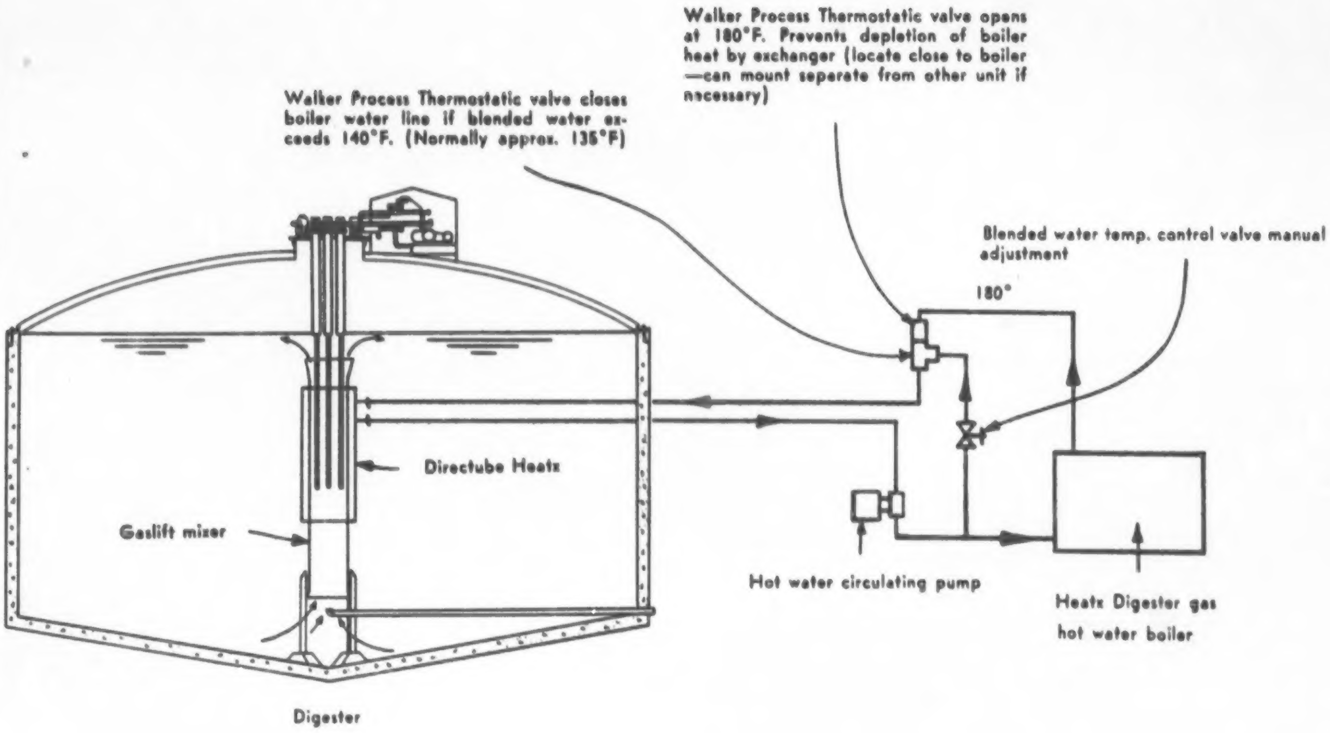
Various devices have been developed to overcome operating problems which have occurred in digestion tanks, particulary scum formation. These devices have been intended basically for agitating the contents of digestion tanks. They have taken the form of both mechanical mixers, with and without draft tubes, and devices for collecting the gas produced and returning it to the tank through perforated pipes or diffusion tubes.

As these mixing devices have come into use and as further research work has been done, it has been found that by (a) mixing heated digestion tanks, (b) feeding the settled raw sludge at a more or less continuous rate, and (c) concentrating the raw sludge before addition to the digester, the size of digestion tanks could be reduced. This is often known as "high-rate" digestion, since the displacement time is shorter than normal.

Another development for the sludge digestion process which should result in additional economies is the draft tube heat exchanger (see Figure No. 7). An adaptation for the draft tube mixer, either mechanical or gas type, has been developed so that it will function as a heat exchange. A jacket is added surrounding the draft tube through which hot water is circulated. Heat is transferred to the sludge as it moves through the draft tube mixer. This adaptation simplifies the heating operation since it is much easier to circulate hot water rather than sludge. This modification also makes use of hot water boilers and results in lower initial costs as well as reduced operation and maintenance costs.

Advancements have been made in vacuum filtration of sewage sludge, particularly in the development of new filter media. These new media include synthetic materials, such as saran, polyethylene, and dacron; stainless steel coil springs; and woven stainless steel belts. New methods also have been developed for aligning and cleaning the filter media, and discharging the dewatered cake (see Figure No. 8). Instead of applying air pressure to discharge the cake, the media is removed from the drum and taken around a small radius roller before being put back on the drum. This action discharges the cake and allows the media to be cleaned either continuously or at frequent intervals with water sprays before it is returned to the drum.

These developments have increased the efficiency of vacuum filtration to the point where it has been possible to bypass the digestion step and dewater raw sludge. Furthermore, polyelectrolytes have been developed which show promise of making it possible to reduce the quantity


Walker Process Thermostatic valve opens at 180°F. Prevents depletion of boiler heat by exchanger (locate close to boiler —can mount seperate from other unit if necessary)
Walker Process Thermostatic valve closes boiler water line if blended water exceeds 140°F. (Normally approx. 135°F)
Blended water temp. control valve manual adjustment
180°
Directube Heatx
Gaslift mixer
Hot water circulating pump
Heatx Digester gas hot water boiler
Digester

Draft Tube Heat Exchanger
As Manufactured by Walker Process Equipment, Inc.

Figure No. 7

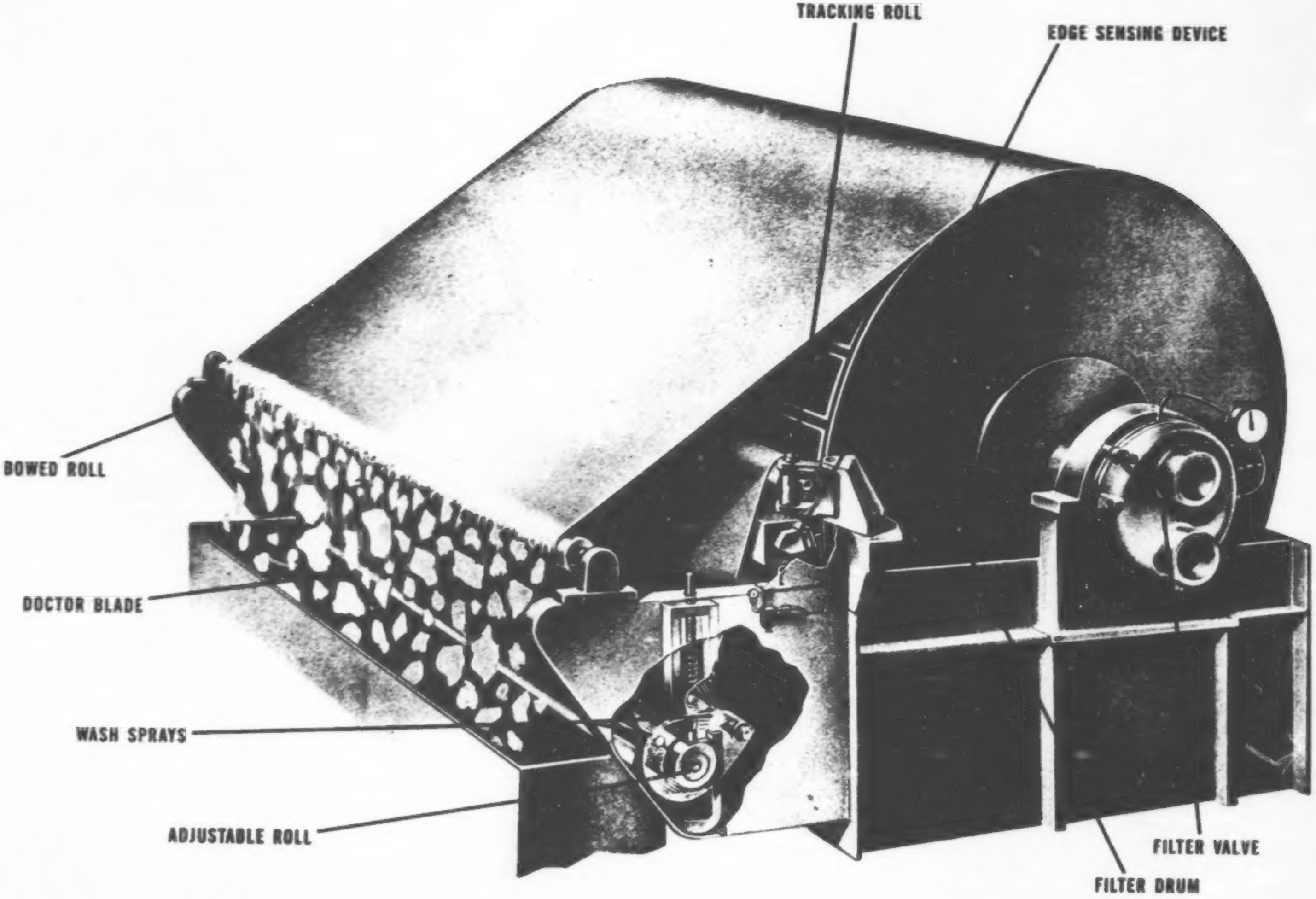


Figure No. 8

Vacuum Filter for Dewatering of Sewage Sludges
As Manufactured by Dorr-Oliver, Incorporated

of chemicals required to condition the sludge for filtration and to obtain greater production from vacuum filters.

Two new developments in the field of sludge thickening or disposal have been the Laboon process and the "Roto-Plug" sludge concentrator. The Laboon process, which has been installed at Pittsburgh by the Allegheny County Sanitary Authority, consists of pre-heating fresh sludge, containing about 10 per cent solids, to about 95 degrees F. before admission to sludge concentration tanks where the sludge remains for about five days. The hot raw sludge solids tend to rise to the surfaces of the tanks, and after withdrawal of the subnatant liquor, the sludge is removed from the bottom of the tanks at a concentration of 15 to 20 per cent solids. This sludge can then be incinerated for disposal.

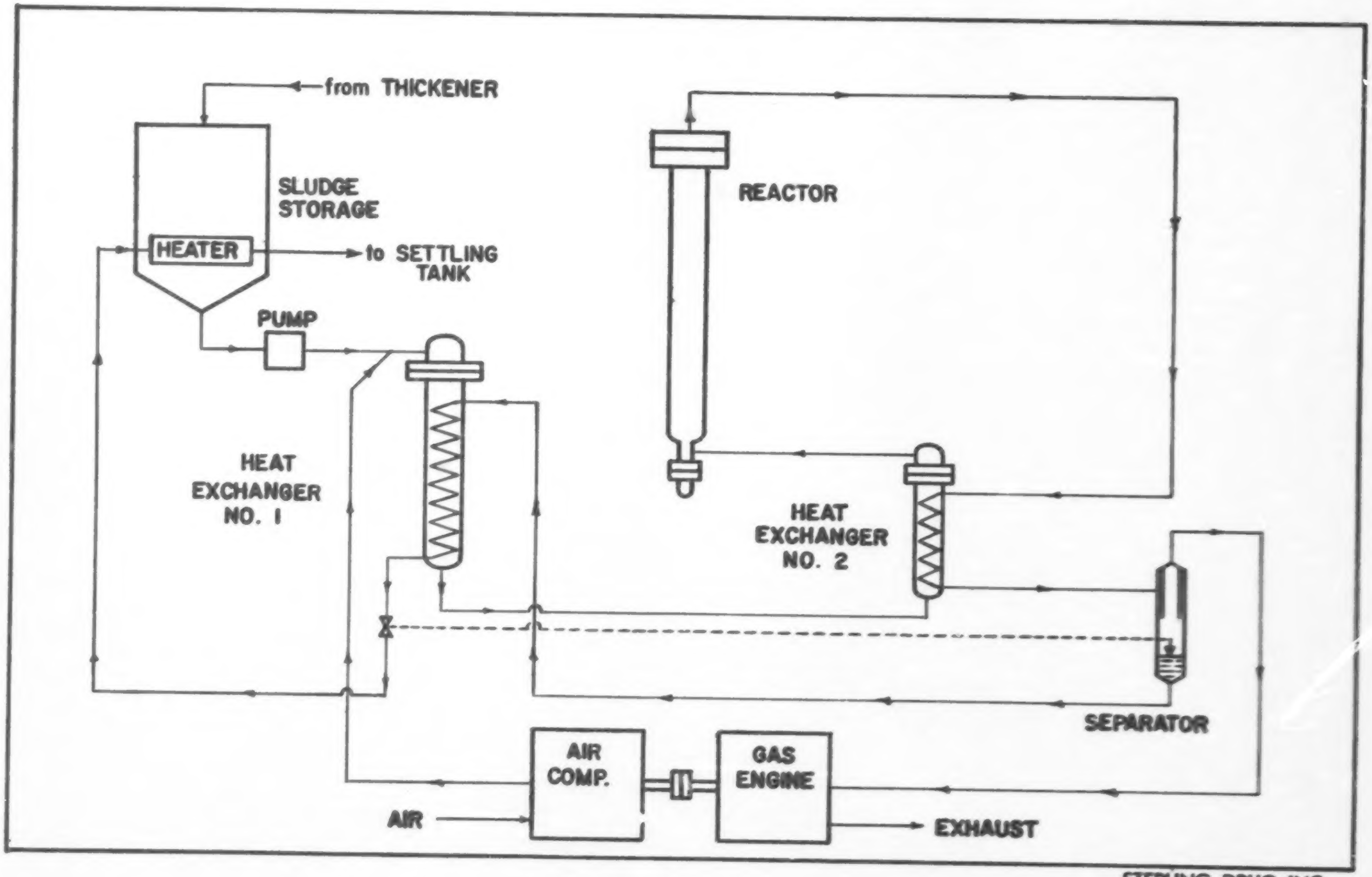
The "Roto-Plug" sludge concentrator is a device which will thicken or dewater raw primary sludge without chemical conditioning. Digested and perhaps secondary sludges will require the addition of fibrous material such as paper pulp. It is composed of a thickener unit and a compression unit. The thickener is a hollow cylindrical unit having a peripheral nylon filter media and flanges at the ends. This drum is rotated as the sludge is fed into it. A substantial part of the moisture drains through the nylon media. The solids deposited into the media form into a rolling mass, or plug, which further dewaters the sludge as it presses against the media. The media is kept clean as the solids depositing on it are picked off by adhesion to the plug. The plug increases in size as more solids are picked up and distends axially over one end flange to be discharged from the unit. The compression unit then further dewaters the sludge by compressing it between two impervious drums and a drum of slotted stainless steel. The dewatered cake is comparable to that from a vacuum filter, 20 to 25 per cent solids, and may be disposed of by sanitary land fill or incineration.

Perhaps some of the most significant and revolutionary developments in sludge disposal in the last few years have been the Zimmermann Process and a method developed in Canada known as the "Atomized Suspension Technique". In the Zimmermann Process (see Figure No. 9), the equipment used includes a reactor, air compressor, heat exchangers, sludge pumps, and an expansion engine.

Pumps introduce concentrated sewage sludge and air into the system in a selected ratio. The sludge is preheated in the heat exchangers to about 400 degrees F., so that oxidation can start with reasonable speed, and it then is forced into the reactor. The temperature in the reactor can be run up to 700 degrees F., the upper limit being the critical temperature of water (the point at which water cannot exist in a liquid state regardless of pressure). At temperatures below 400 degrees F., oxidation appears too slow for practical application, although complete oxidations have been carried out as low as 300 degrees F. Normal reactor temperatures are near 500 degrees F.

Contents of the reactor move forward continuously to the first heat exchanger where some excess heat is removed to preheat incoming sludge. Next, the contents are separated in a steam separator into gas and water.

ZIMMERMANN OXIDATION PLANT
FOR 100 TONS OF SEWAGE SLUDGE PER DAY



STERLING DRUG INC.
NEW YORK, N. Y.

Figure No. 9

This water is used further to preheat the incoming sludge. Ultimately its heat is exhausted in the storage tank heater.

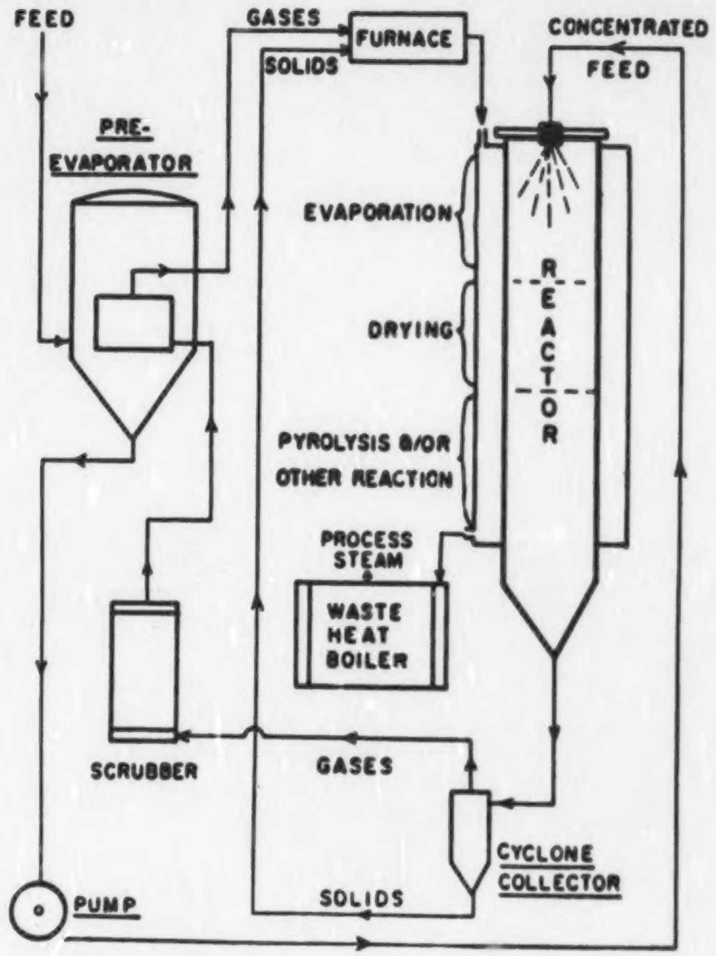
The liquid contains the ash, which can be pumped to a lagoon or fill. Containing no more than 10 to 15 per cent organic matter, depending upon the degree of oxidation desired, the ash will not create obnoxious odors. In large units the gases previously separated then are expanded to run a directly coupled air compressor.

A key factor in the Zimmermann process is the concentration, i.e., per cent solids, of the sludge fed to the reactor. If sludge concentration is high enough, the reaction is self-sustaining and may produce a surplus of heat energy. If sludge is too dilute, heat energy may have to be supplied to keep the reaction going.

This process is to be used at the Southwest Treatment Works of the Metropolitan Sanitary District of Greater Chicago, and at the Wheeling, West Virginia sewage treatment plant.

In the Atomized Suspension Technique (see Figure No. 10), raw sludge is concentrated to approximately 10 per cent solids and collected in a storage tank. After passing through a disintegrator to chop up fibrous materials, it is pumped to the top of a reactor tower. Here it is atomized with pressure nozzles and passed into the tower.

Wall temperatures in the tower range from 1400 degrees F. at the top to 1,000 degrees F. at the bottom. Thus, water in the spray flashes into superheated steam, and solid particles dry so rapidly as they fall that they are easily burned to a dry, fine ash when low pressure air is introduced near the tower bottom. Odors and bacteria are completely destroyed by the high temperatures. A condenser cools the steam, and the ash is carried away entrained in the condensate.



Atomized Suspension Technique Flow Sheet
(From Paper Presented by K. L. Pinder and W. H. Gauvin
at 1957 Purdue Industrial Waste Conference)

Figure No. 10

The heat in the exhaust steam from the reactor would be recoverable for some useful application and might reduce what appears to be a rather costly method of heat production.

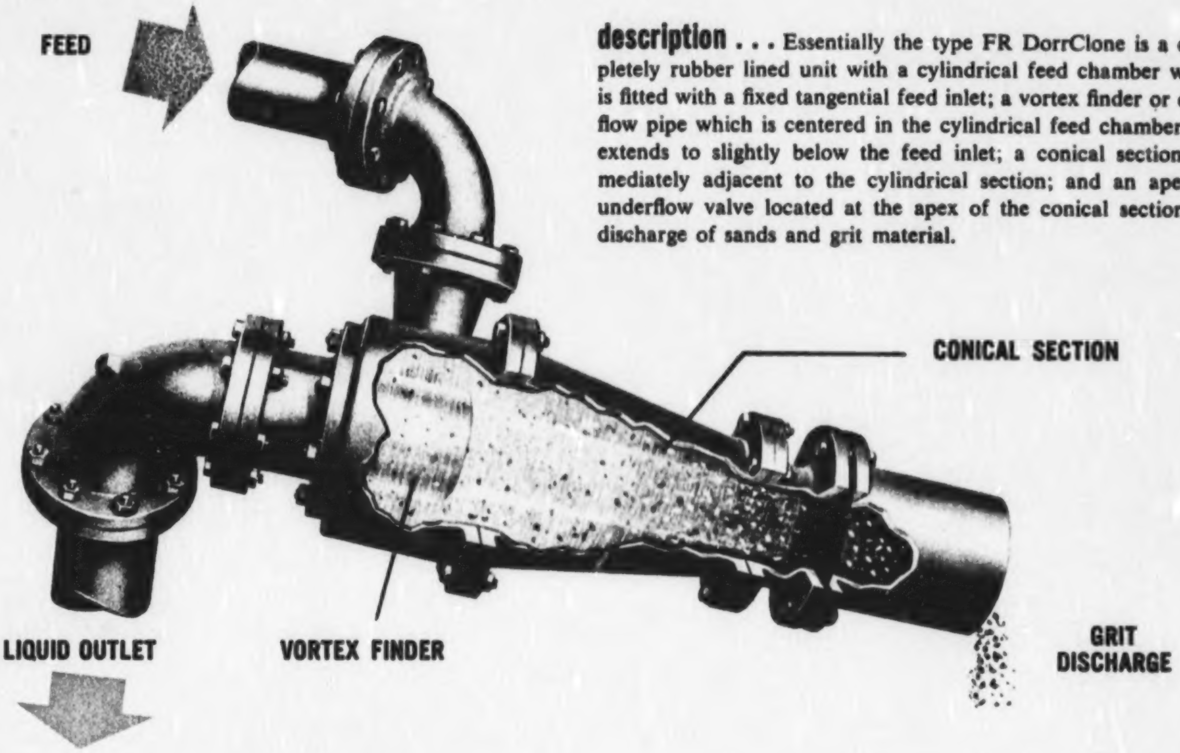
It is probable that the AST concept will be more adaptable to industrial wastes than domestic, for some engineers feel that the cost of creating the high temperatures will be prohibitive.

There have also been a number of new developments in the phases of waste treatment involved with the separation of liquids and solids, as well as secondary treatment. Most of these have been developed primarily to effect economies - either in first cost or operating and maintenance costs.

One of these developments used for grit removal (see Figure No. 11), consists of a rubber-lined cylindrical feed chamber, fitted with a tangential feed inlet and an overflow pipe centered in the chamber slightly below the feed inlet. In degritting raw sewage, the sewage enters the apparatus through the tangential inlet and centrifugal force throws the grit into a conical discharge tube attached to the cylinder.

Other developments include the design of mechanical equipment to accomplish more than one process in the same basin. Among the units that are available are those which combine pre-aeration and settling; pre-aeration, grit removal, and settling; aeration and final sedimentation; and settling and sludge thickening. Except for the last combination, these units primarily are applicable for smaller plants. Going one step further, a number of manufacturers have developed factory-built

description . . . Essentially the type FR DorrClone is a completely rubber lined unit with a cylindrical feed chamber which is fitted with a fixed tangential feed inlet; a vortex finder or overflow pipe which is centered in the cylindrical feed chamber and extends to slightly below the feed inlet; a conical section immediately adjacent to the cylindrical section; and an apex or underflow valve located at the apex of the conical section for discharge of sands and grit material.



DorrClone Grit Classifier
As Manufactured by Dorr-Oliver, Incorporated

Figure No. 11

or "package" plants for small communities, institutions, and business establishments, which provide a modification of the activated sludge process known as total oxidation or aerobic digestion. The process oxidizes the liquid and solids by holding them for an extended time (24 hours normally) and providing an excess of air. The biggest boost to this type of plant has been the development of the epoxy resin coatings for steel which greatly reduces corrosion. Many of the smaller plants are factory-assembled and merely placed on a concrete pad at the job site, connected to the sewers and power supply, and put into operation.

There have also been a number of developments in secondary treatment. One of these relating to trickling filters is the development of plastic media which is designed to provide maximum surface area per volume.

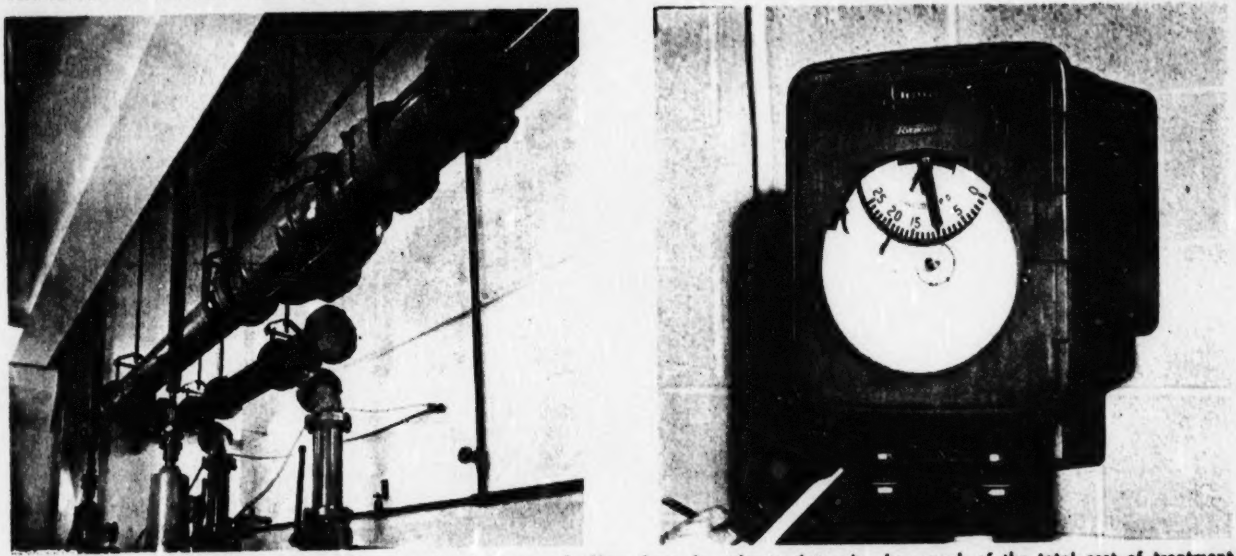
With respect to the activated sludge process, there has been a great deal of work during the past few years on mechanical aerators. Several manufacturers have also developed an aeration combination of mechanical and diffused air, utilizing a sparge diffusion ring and a motor driven impeller. There have also been some developments of non-clog diffusion equipment and low pressure diffused air systems.

There have also been developed, mostly through the ingenuity of plant operators having one difficulty or another, a number of modifications to the activated sludge process. Most of these variations have developed more stable systems by using higher sludge concentrations in the aeration basins, reaeration of the sludge from the final sedimentation basins before returning it to the aeration tanks, and control of both the sludge concentration and the aeration rate.

In some areas a number of raw sewage lagoons for sewage treatment have been built in the past ten years. The design of these lagoons provides about one-half to one acre of water surface for each 100 persons tributary to it and about a 3 to 5-foot water depth in an earth diked basin. A biological cycle is set up between bacteria and algae. The algae give off oxygen in the photosynthesis process which the bacteria utilize along with the organic matter in the sewage. Where enough land and a suitable location are available, this method of treatment will provide a very economical method of secondary treatment, primarily because of the low cost of operation and maintenance. Continuing research is being conducted with respect to a satisfactory basis of design, and the effects of recirculation and mechanical aeration in an effort to reduce the required area.

Probably nothing has affected sewage treatment plant operation more than the introduction of adequate recording and control equipment. This, combined with research in the field of automatic laboratory testing, is bringing the automatic plant closer and closer to reality. One of these developments is the magnetic flow meter (see Figure No.12). By applying a uniform magnetic field around a section of stainless steel pipe, the volume of flow is measured by the electrical impulse created by the liquid flow through the magnetic field, thus the problem of clogging in conventional meters is eliminated. Another recent development is a meter to determine sludge density (per cent solids) by the use of

THE SEWERAGE MANUAL—1960 EDITION



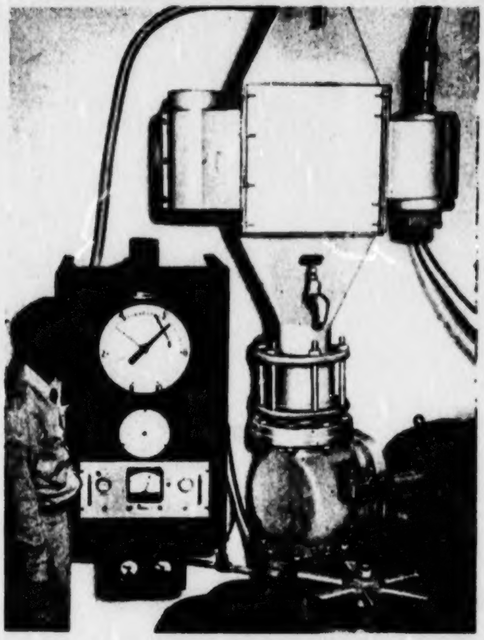
At Newport, R. I., the influent flow includes a portion from a nearby Navy base. In order to determine how much of the total cost of treatment should be billed to the Navy, a Foxboro magnetic flow transmitter was installed (left) with a Foxboro Dynalog Recorder as shown (right).

(From The Sewerage Manual - 1960 Edition, Public Works Publication)

Figure No. 12

nuclear radiation. The meter can also be used (see Figure No. 13) to control sludge pumpage from primary sedimentation tanks to digesters, vacuum filters, or other sludge treatment processes. As shown in diagram, the pump would start at a predetermined interval and pump until the sludge reached a preselected minimum density. This scheme eliminates filling digesters with excess water or treating extra water with the sludge.

NOTE: Since design and construction of waste treatment works must necessarily be addressed to the problems of waste treatment and of plant operation and maintenance, much of the above applies also to the following subject which deals with the operation and maintenance of waste treatment works.



Installation of an Ohmart Sludge Density Controller at the Los Angeles County Sanitation District's Joint Disposal Plant. Diagram below shows components.

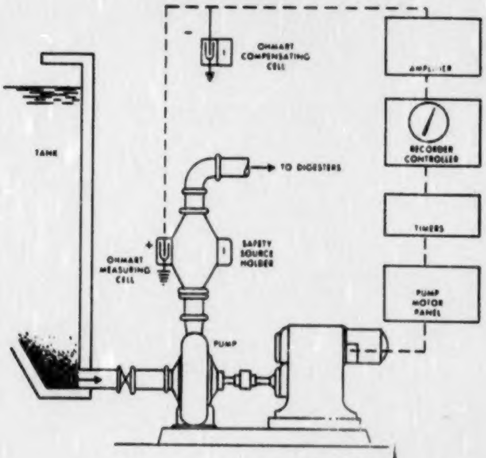


Figure No. 13

OPERATION AND MAINTENANCE OF SEWAGE AND WASTE TREATMENT WORKS

General

Upon completion of the design and construction phases of waste water treatment installations, the owner must provide adequate funds for operation and maintenance. Although capital costs are generally financed by long-term bonds, the operation and maintenance costs must come from current budget funds which, in many cases, are subject to severe competition from other functions within the corporate organizational structure.

However, the problem of funds allocation must be equitably resolved to guarantee optimum operation and maintenance of the treatment facility, as well as to protect what generally represents a sizeable investment to the community or industry. A listing of the major annual cost items would include competent personnel, operating controls, preventive maintenance, equipment replacement and modification, power, and other utilities.

The Problems Involved

The problems associated with the operation and maintenance of a waste treatment works are as varied and complex as other manufacturing industries having as their purpose, the converting of raw materials into valuable useable products.

Procuring and retaining dedicated, capable personnel is a major problem in waste treatment operations even when funds are adequate. The lack of sufficient funds poses an intolerable situation which can result only in poor operation, lowered plant efficiency, and often deterioration of the physical plant.

A modern sewage treatment plant is a very complex system of structures, pipes, valves, meters, pumps, motors and related appurtenances, all subject to wear and deterioration through use, and from the corrosive and abrasive nature of the sewage it processes. The tendency of humans to discard any and all materials to the sewerage system causes treatment plant problems, many of which can be handled more economically and practicable by methods other than the sewer.

Many types of industrial wastes have a deleterious effect on sewage treatment, and on the treatment plant and its appurtenances. Explosive and flammable substances should never be discharged to the sewerage system. Examples are dry cleaning fluids, chemical solvents, and gasoline. The presence of oil interferes with sedimentation and vegetable oils exert a high oxygen demand on biological treatment processes.

Traditional Practices

Maintenance of Plants - The term maintenance may be defined as the art of keeping plant grounds, equipment, structures and related facilities in suitable condition to perform the services for which they were designed. The effectiveness and efficiency of maintenance will reflect the concern of management and in turn the attitude of employees. A plant that is well maintained and operated will perform at a high efficiency, both from the standpoint of economy and waste treatment.

Maintenance should be carried out in a manner which prevents emergencies or unscheduled shut-downs by orderly preventive maintenance practices. Experience has shown that a basic maintenance program should include the following elements:

1. A good housekeeping program that produces a clean, neat and orderly plant in which the employees can efficiently carry out their responsibilities and which presents a pleasing appearance to the public supporting the facilities.
2. A systematic plan for execution of daily operations, maintenance, inspections, and personnel activities.
3. A system of records and record keeping which willreflect all necessary details of design, construction, operation, maintenance, costs, and future needs.
4. A schedule of regular meetings of personnel for planning, training and instruction.
5. A recognition of the accomplishments of personnel through an incentive awards and public information program.

New Materials and Equipment and New Uses of Older Materials and Equipment

Maintenance problems and cost are reflected in the type or quality of materials available for construction of the structures and equipment, and the quality of materials from which the replacement parts are manufactured.

The materials most resistant to corrosion, erosion, and wear should be used within the economic limits of manufacture and general use. Normal economic cost limits must be disregarded when problems of difficult location, continuous plant operation, or plant and personnel safety are involved. The best use consideration in the selection of materials may often be the most economical in the long term due to savings in labor and out-of-service time.

Many new materials are coming into use which reduce maintenance requirements and improve plant operation and maintenance, and older materials are being adapted to new uses for these purposes. In addition to those discussed previously under the subject of design and construction of sewage and waste treatment works, they include:

Stainless steels in reactors, valves, tanks, shafts, pump impellers, pipes and fittings, and laboratory equipment where wear, rust and corrosive materials are a problem. Tungsten carbide is being used for valve facings and Buna-N rubber for sludge pump stators because of the resistance of these materials to wear and corrosion.

Titanium, silver and platinum are used in chlorinators for their excellent resistance to the corrosive action of chlorine and chlorine compounds.

Because of their resistance to corrosion and wear, and their impermeability, pliability and adaptability to precasting, plastics of a wide variety are used for trickling filter media, linings for waste treatment lagoons, weirplates, pipe lining, gaskets, seal rings, sleeve bearings and floor coverings.

Aluminum alloys are used for weirplates, stopgates, grating, railing, gas safety equipment (flame traps, relief valves, pressure regulators) and electrical boxes, again where rust and corrosion are problems.

Molybdenum alloy is widely used in rebuilding bearings, pump shaft sleeves and other machinery parts subject to severe wear. This is accomplished by metalizing or metal spraying the worn parts to restore them to the original design dimensions.

A wide variety of paints and protective coatings manufactured from plastics, epoxy resins, rubber, neoprene, bituminum derivatives and fiber glass are used for their long life and corrosion resistance.

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RESEARCH AND DEMONSTRATIONS TO DEVELOP WASTE TREATMENT PROCESSES WHICH WILL MAINTAIN WATER QUALITY SUITABLE FOR REPEATED REUSE

Oversimplifying a very complex situation, the water resources problem confronting the United States from now on is one of making its relatively fixed supply meet a rapidly increasing demand by providing the right quantity of water of the right quality where it is needed.

To meet needs we must develop our capturable water resources up to their maximum dependable amounts and pursue an aggressive, effective program of pollution prevention and control that will maintain a high level of water quality in the ground, lakes and streams across the country. A high level of water quality must be maintained to permit the repeated reuse of the same waters as they flow past each city, industry, farm and recreation area.

Water supply and pollution trends show that one of the most pressing problems in water quality management is the need to develop new treatment processes which will remove much more of the contaminants from municipal wastes than is possible by present biological methods. The volume, strength and complexity of future municipal wastes can only result in the discharge of larger and larger amounts of impurities into badly needed water resources if we continue to apply presently-known treatment processes only.

A good part of the municipal pollution problem is probably in the conception of today's "complete treatment." The use of this phrase has been very misleading to the taxpayer and perhaps even to the technicians. To achieve what is called complete treatment, continued application of conventional biological treatment processes is made.

What is accomplished by today's complete treatment? A fairly good job is done in removing oxygen-consuming materials, generally 75-90 percent. About the same amount is accomplished with respect to suspended materials, although in so doing another problem not yet satisfactorily solved is created which is, what should be done with the separated sludge? Some biological stabilization of the effluent is achieved by oxidizing nitrogen compounds to nitrates, only to create in a growing number of instances serious algae problems in downstream waters. A fraction of some of the dissolved organics is removed, such as synthetic detergents and other new commercial and industrial chemicals. This has been called "complete" treatment and the receiving stream has been relied on to complete the job.

What is it that present-day treatment methods do not remove? They do not remove 10 - 25 percent of the B.O.D. nor remove but a fraction of the dissolved organic and mineral solids which normally account for 60 - 80 percent of all solids in municipal sewage. Present methods remove only a small amount of the new wastes entering sewerage systems in increasing numbers, varieties and amounts--detergents and other household chemicals, industrial chemicals of a wide variety, and industrial process wastes of a highly complex nature. Neither do they remove the nutrients that support algal growths and consequent taste, odor, and nuisance problems.

Each water use adds increments of wastes that are not removed by biological treatment. If we are to meet water needs through repeated reuse, much more of the impurities must be removed from municipal wastes. To do this new treatment processes must be developed, probably based on entirely new concepts and principles, that will achieve what approaches conversion of waste waters to fresh waters. This will require a major research program and the best scientific minds in government, industry and universities. It will require the utilization of physicists, physical chemists, and other scientists not yet fully brought to bear on water pollution problems.

The Advanced Waste Treatment Research Program

In amending the Federal Water Pollution Control Act in 1961, the Congress recognized the need for reuse of water and, consequently, the need to develop much more effective processes for removing contaminants from waste waters. The 1961 Amendments direct the Secretary of Health, Education, and Welfare to "develop and demonstrate under varied conditions (including conducting such basic and applied research, studies, and experiments as may be necessary): (A) Practicable means of treating municipal sewage and other waterborne wastes to remove the maximum possible amounts of physical, chemical, and biological pollutants in order to restore and maintain the maximum amount of the Nation's water at a quality suitable for repeated reuse;"

In response to this directive a major research project has been established in the Public Health Service, presently called the "Advanced Waste Treatment Research Program." The objectives of the program are twofold: (1) to reduce the level of pollution of the Nation's water resources to the minimum practicable level to permit repeated downstream water uses, including recreation and propagation of fish and aquatic life and wildlife; and (2) to reclaim waste waters for deliberate reuse by the same municipalities and industries producing the waste waters. Similar work begun by the Public Health Service in 1960 has been made a part of this major research project.

Since biological treatment methods, even after years of refinement, do not begin to remove all the contaminants in today's wastes, the Advanced Waste Treatment Research Program is directed towards developing chemical-physical processes which separate the wastes from water or the water from the wastes. The long-range program is planned to follow the basic research-pilot study-demonstration plant procedure as is implied by the language in the 1961 Amendments.

Economic Factors

Much has been written about the economic worth of water and most people generally agree that water is, without question, one of our best bargains. Often, however, people fail to consider all the factors which influence costs in water use.

Our fresh water resources not only provide water for municipal use but serve also to dilute and transport our wastes. With an expanding population, both needs will be intensified. Even if all wastes were being given complete conventional treatment, our rivers and streams would reach their capacity for assimilating wastes at some future time. This condition has already been experienced at a number of locations. Also, even if these surface waters could be maintained at a quality permitting conversion to acceptable water supplies by means of conventional water treatment, their amount is fixed and a point in time would be reached when there would be no more developable inland fresh waters. These facts were brought out quite clearly in the comprehensive report published in 1960 by the Senate Select Committee on National Water Resources. The basic solution to these problems must be found in a more efficient utilization of our existing water resources through multiple reuse.

Because the feasibility of an advanced waste treatment system is dependent upon economic considerations, development of reliable cost data is an essential responsibility of the AWTR Program. Such data must be obtained in order to provide a meaningful basis on which to evaluate research and developmental work. Unfortunately, specific cost information regarding advanced waste treatment processes is non-existent at this date. As a result, it seems desirable to obtain at least baseline information on cost goals by assessing the costs of existing water and waste treatment operations which an advanced waste treatment system would ultimately replace.

Ideally, an analysis such as this should provide cost information in as much detail as possible. This goal, however, cannot be attained. In most cases, detailed breakdowns of various water and waste treatment costs simply do not exist; often, even when data are available, true costs are obscured by unrealistic bookkeeping and non-uniformity in costing procedures, let alone the adjustment of costs upward or downward for inflation or other price changes.

Fortunately, information is available on average costs of various elements of today's water and sewage treatment technology. This information, based on data from national surveys such as those conducted by the Public Health Service, the Census Bureau, the American Water Works Association, and the American Public Works Association, provides the foundation for the analysis below. It is hoped that by utilizing these several extensive, broad, and independent surveys, deviations from average figures will be minimized.

It is recognized that cost goals for specific projects cannot be developed from national average costs. These figures will not indicate projected advanced waste treatment costs nor will they resolve the question of which method of supply should be used. They are presented here only as a preliminary guide to the economics of water renovation. It should also be understood that in an advanced waste treatment system, it is possible to make maximum use of existing facilities without retiring valuable property. In some cases it may be more economical to completely replace an existing facility but in most cases this is unlikely.

Water supply and waste treatment costs can be ascribed to the major elements of the typical municipal water-use cycle depicted in the following diagram. As shown, both water and sewage treatment should be coupled and considered together in a realistic total water-use cycle. The first cost in the cycle is for development of the source and for transmission to the treatment plant. The average cost over the United States for these functions is about 4 - 6 cents /1000 gallons. These costs ran[illegible] from 0 to about 30 cents/1000 gallons, and prevailing high costs for development and transmission approach 22 cents/1000 gallons. These figures, as do all those presented in this section, represent total costs including operation and maintenance plus amortization of the original investment.

Treatment costs range between 0 and 9 cents/1000 gallons. The national average is about 6 cents/1000 gallons, with prevailing high costs perhaps a penny higher. Since treatment costs vary directly with the quality of the supply, improved quality of our fresh water resources due to the introduction of advanced waste treatment processes would decrease the cost of water treatment in downstream communities, even those not employing advanced treatment systems.

Water distribution and waste collection constitute a major part of the water-use expense. Distribution averages 17 - 19 cents/1000 gallons, while collection averages about 4 - 6 cents/1000 gallons over the United States. These costs, unless a dual-distribution system was considered, would probably be unaffected by any advanced waste treatment system.

Following waste collection in the water-use cycle is sewage treatment and disposal. The average cost of these operations is 4 - 6 cents/1000 gallons, varying from 0 to 8 cents/1000 gallons.

It would be extremely unrealistic if we stopped our discussion of the cost of water use at this point. In addition to these obvious costs, other costs of today's water use should be considered. In areas where ground water is the conventional supply, lowering of the ground water table through pumping may increase pumping costs to all common users of that underground source. Water removal from conventional sources may deprive many users of a cheap water source, forcing use of more expensive water. Natural purification in our streams and lakes must logically be included as an element of waste treatment. Indeed, we design our treatment plants around the assimilative capacity of receiving waters. Although many of us do not like to accept the fact that natural treatment costs money, it does. Fish kills, game fish deterioration, and loss of recreational usefulness of the water are all economic effects. Another of these indirect costs in the incremental cost imposed upon the downstream water user which results from the necessity of removing additional pollutants which his upstream neighbor has introduced.

While the above are examples of indirect costs of our present water-use cycle, each could be measured in terms of dollars. Other indirect effects cannot be quantified in this way, since they are very real. For example, water-based recreation in non-polluted, aesthetically acceptable surroundings is an economic asset as would be the assurance that chemical, biological, or radiological pollutants do not exert subtle, cumulative effects on the health of man.

Aside from these indirect or uncertain costs and benefits of our present water-use systems, can advanced waste treatment systems be prepared to compete now with conventional water supply and waste treatment?

As an estimated cost goal, advanced waste treatment costs can be equated roughly with the costs of present functions of source development, transmission, water treatment, waste treatment, and disposal. The total is about 17 cents/1000 gallons on a national average, and approximately 35 cents/1000 gallons in prevailing high cost areas of this country.

Definitive cost goals have not been established for advanced waste treatment. It would be impossible to do this with current knowledge. Besides, the only realistic cost goal which can ever be stated with certainty is that the cost of water renovation must be the very minimum that science and engineering can achieve - anything greater will impose an inexcusable handicap on the country's economic growth.

Finally, it is appropriate to conclude that advanced waste treatment is competing for the entire municipal water market and much of the industrial. That it is the core of a new policy of water conservation and management. In fact, the purpose of the Advanced Waste Treatment Research Program is to insure a continuing supply of water, suitable in quantity and quality, to serve the widest possible range of human needs.

Technical Approaches to Advanced Waste Treatment

Two important objectives must be achieved if the total concept of advanced waste treatment is to be feasible. First, it will be essential to concentrate the impurities in municipal waste water into small volumes and provide for permanent disposal of this concentrate. Second, it will be necessary to produce purified water of a quality suitable for direct reuse. Concentrated wastes removed by advanced waste treatment processes cannot, of course, be discarded back into surface waters. If this were done, stream pollution problems would not be diminished and downstream water users would have to remove the same contaminants again and again. The development of methods for permanently disposing of concentrated impurities is, therefore, an important part of the concept. Efficient removal of contaminants will result in the production of water of excellent quality. Provision should be made for deliberate direct reuse of this water by the community or industry since in most cases, it would be wasteful to discharge an excellent water into a stream which is less pure, perhaps much less pure, than the treated discharge. The development of a successful advanced waste treatment technology, therefore, could lead in one step, to the alleviation of both water pollution and water supply problems.

From a technical standpoint, advanced waste treatment may be looked upon as a two-step process: (1) separation of concentrated contaminants from the purified water "product," and (2) disposal of the concentrated contaminants in a way that renders them forever innocuous. Research is necessary, therefore, on both "separation" and "permanent disposal" techniques. These two elements of advanced waste treatment are related economically since, in general, the further waste is concentrated, the higher the cost of concentration but the lower the cost of disposal.

Although their objectives are similar, there are a number of important differences between advanced waste treatment and saline water conversion. First, there is the problem of permanent disposal of the concentrated wastes. When a saline water conversion plant is situated on the ocean's shore, concentrated waste brine can be dumped back into the sea which serves as an infinite waste sink. However, in Kansas City, Cincinnati or any inland city, there is no suitable place to dispose of the concentrated wastes from a water renovation plant. Therefore, the concentrated wastes must be disposed of permanently and advanced waste treatment researchers must strive for product-to-waste ratios which are much higher than those considered satisfactory for saline water conversion. While a 1:1 ratio, i.e., one volume of waste brine for each volume of product, is satisfactory for desalination ratios of at least 1:100 and very possibly 1:1000 must be achieved in waste water renovation. Such a requirement makes one problem much different technically from the other.

Second, the types of impurities of challenge in waterborne wastes are quite different from those found in saline waters. In waste waters there are obviously significant quantities of organic materials which are not found in large amounts in the sea. There may also appear a broad spectrum of industrial wastes as well as biological and even radioactive pollutants.

Third, the physical and chemical characters of the feed streams are distinctive. Theoretically, the carrier fluids for both saline waters and waste waters are the same - H_2O. Practically, however, the feed streams are quite different - one is salt water, the other fresh. This difference is reflected in the properties of the two streams; for example, the viscosity, thermal conductivity, ohmic resistance, freezing point depression, boiling point elevation, and corrosivity. These factors can have a significant bearing on the technological feasibility, engineering process design and, most important, on the economics of the various separation techniques under study.

Fourth, waste water renovation is a dynamic problem, while saline water conversion is a static problem. In any one location, for example, the feed water composition to a desalination plant should remain relatively constant. It is not expected that the composition of the sea will change appreciably over the next 50 to 100 years; but in an advanced waste treatment plant, the process must be capable of accommodating a feed stream which is changing in composition and concentration from hour to hour. It also must accept changes from day to day, from season to season, and certainly long-term changes from year to year. To illustrate, 25 years ago no synthetic detergents were found in waste waters; today they are. Today there are no soluble packaging materials present, but five years from now, it is anticipated that such materials will be a common component of municipal wastes. Feed composition will vary geographically as well. More and more, the composition of a municipal waste stream will reflect the wastes from the area's industrial complex.

Finally, the types of treatment processes which must be considered encompass not only those capable of purifying saline waters but many others based on entirely different principles of separation. This is required by the dissimilar nature of both concentration and composition of impurities.

Separation Processes

It is conceivable that almost any physical-chemical principle of separation is applicable to advanced waste treatment. Principles under active consideration include adsorption, electrodialysis, emulsion separation, evaporation, extraction, foaming, freezing, hydration, ion exchange, and chemical or electrochemical oxidation. None of these unit operations have been applied to municipal waste treatment.

Adsorption

One of the most promising processes in the technology of advanced waste treatment is adsorption - the concentration and collection of contaminants at the surface of a solid. The solid or "adsorbent" can be removed from the liquid by simple mechanical means, carrying the associated impurities along with it. Use of activated carbon adsorbents is a proven technique in water purification for removing the same soluble organic contaminants that are refractory toward conventional waste treatment. In water purification plant application, the concentration of taste- and odor-causing contaminants is extremely low, far below the concentrations of materials which must be eliminated in waste water renovation. Since an adsorbent can only collect a limited quantity of material before it becomes saturated, present methods would be economically impractical for advanced waste treatment unless the adsorbents used were very inexpensive or could be economically regenerated to allow multiple reuse. Research is required, therefore, both in low-cost adsorbents and in low-cost regeneration methods.

At the other end of the scale lie the high-quality, high-capacity, high-cost adsorbents. The many varieties of activated carbons and charcoals fall in this group. Such substances will be practical only if regeneration and multiple reuse are possible. Granular activated carbon is now in use which can be regenerated by a "thermal" process, i.e., the adsorbed materials are baked off at high temperature. Studies are needed to determine whether existing methods and equipment for this process can be economically applied to the complete renovation of municipal wastes. Other methods of regeneration, such as steaming and extraction must be evaluated also. One advanced waste treatment contractor has shown that, under the proper conditions, two different adsorbents may be used in tandem to give better performance than is possible with either of the adsorbents individually. Methods for producing appreciably cheaper activated carbons have been suggested; also for developing high capacity, regenerable synthetic adsorbents. Several of these are under study.

Electrodialysis

Electrodialysis is a fairly common laboratory technique for concentrating ionic materials in solution. For this process, electrodes are used to impress an electrical field across a cell through which the liquid to be purified is flowing. This field causes cations (positive ions) to migrate toward the cathode and anions (negative ions) toward the anode. If there is placed between the two electrodes a number of membranes which are alternately cation- and anion-permeable, then both cations and anions can be removed from alternate compartments and concentrated in the intervening compartments. Electrodialysis does not appear to offer economical conversion of waters containing high concentrations of ionic impurities, such as sea water, but may have appreciable promise for treatment of waters of lower ionic strength such as sewage and waste waters.

Electrodialytic purification of brackish waters is already an accomplished fact in a number of plants throughout the world; its potential for waste water renovation is now being assessed. Several possible innovations to conventional electrodialysis are of interest. It has recently been demonstrated that it is possible to recirculate a waste carrier stream continuously and to discharge essentially solid contaminants from this stream by precipitation. If this technique could be applied to waste waters, it would offer great advantage because of its very high, very desirable product-to-waste ratio. A limitation to conventional electrodialysis is the sharply increasing power requirement necessary to reduce ionic concentrations further and further below roughly 500 - 700 mg/l. Possible methods are being investigated for overcoming this limitation. Another area requiring study is the synthesis of new membrane compositions capable of conducting even large organic ions such as are found in municipal waste streams. To make electrodialysis more generally effective for removal of both inorganic and organic contaminants, several methods have been considered for converting non-ionic organic molecules to ionic form.

Evaporation

It is known that waste water streams can be purified by distillation. Experiments by the Public Health Service have shown that the chemical oxygen demand (COD) of secondary sewage plant effluents can be reduced from feed to distillate by at least 98-99 percent in a simple, signle-stage vacuum evaporation. At present heat costs, single-stage evaporation cannot be accomplished economically on the large scale required for extensive waste water renovation. Through heat economization, however, the evaporation process may be best suited to handle the feeds containing complex and variable impurities required in waste water renovation.

There are several ways in which heat economy may be achieved. Among these are multiple-effect evaporation, multi-stage evaporation and the vapor recompression still. Variations of the simple vapor recompression will be studied for their economic application to advanced waste treatment.

A process of interest for centuries is solar distillation - the use of the sun's free energy to distill water. Studies of solar intensity indicate that this process may be applicable in cold weather as well as warm weather areas. Conventional solar distillation is in itself a simple process not likely to be applicable to waste water renovation. However, by certain modifications it may prove feasible. For example, by use of forced convection of water vapor and an external condenser which would provide reuse of solar energy, it may be possible to achieve the advantages of multiple-effect evaporation. If solar distillation cannot be used as a primary separation technique, it may have use as an economical method for further concentration of wastes following some other initial process.

In any evaporation process, it is important that, although a number of problems remain to be solved in developing practicable processes for waste water renovation, certain of the major difficulties encountered in evaporation of more highly concentrated solutions such as sea water, are minimized when municipal wastes constitute the feed stream to the evaporator. Because of the relatively low concentration of impurities in waste water feed, it is possible to perform most of the evaporation from rather dilute solution. This means that the bulk of the water product may be obtained in equipment which is free of appreciable boiling point rise and of corrosion and scale problems.

Extraction

Solvent extraction is yet another possibility. It should be theoretically possible to remove either the contaminants from the water or water from the contaminants. The better process would be to remove the contaminants from the water since there is much less material to remove. In this process a solvent would be introduced into the bottom of an extraction column and by rising up the column would come in direct, intimate contact with the feed stream passing downward countercurrently. With the proper solvent, contaminants would be removed from the feed by dissolving preferentially in the solvent. The solvent-contaminant solution or "extract" could then be led into a separator in which the solvent and the contaminants are parted, perhaps by a slight change in temperature.

Even if all contaminants were not removed the solvent extraction may be of value for selective removal of certain classes of materials.

The major concerns with extraction are that the feed would be contaminated by the solvent and create a secondary pollution problem, or that the contaminants would be more difficult to remove from the solvent than they were from the water in the first place

The second approach is to extract the water away from the contaminants. This possibility is now being studied for desalination purposes. It can be accomplished by use of secondary or tertiary amines as the solvent, but its feasibility in the treatment of wastes has not been studied.

Emulsion Separation

Another category of separation by liquid-liquid contact involves the phenomenon of emulsion formation. Certain solutes tend to concentrate in the monomolecular layer exactly at the interface between immiscible liquids. For organic solvent-water systems, molecules having hydrophilic and organophilic ends exhibit this tnedency. Therefore, an "extraction" can be carried out in which the extractive capacity and the rate of extraction depend not on the volume of solvent used, but on the interfacial area between liquid phases. Such a separation can be carried out using a relatively small volume of solvent if a fine emulsion is generated. The emulsion phase can subsequently be removed and "broken" to recover the solvent for recycle to the system. Preliminary experiments on the applicability of this technique for advanced waste treatment are now in progress.

Foaming

The foaming process, another possible separation technique, is similar to emulsion separation except that a gas forms the second phase of the system rather than another liquid. "Foaming" should be distinguished from "froth flotation." Froth flotation, a principle which has been used in metallurgy and in waste treatment for a number of years, operates on suspended particulate matter but not dissolved materials. It operates by causing air bubbles, introduced into the bottom of a tank, to associate with the particulate matter by adhering to it, and thus decrease its density artificially. This causes the particles to be carried upward and out of the bulk stream because of their greater buoyancy.

In addition to removing suspended matter, a second fundamental separation mechanism occurs which causes dissolved materials to be simultaneously removed from the bulk liquid. This occurs because all water-soluble organic compounds are surface-active to some extent; that is, they tend to concentrate at a gas-liquid interface. If the foam near the air-water interface is removed the soluble compounds present are removed. This is simple, single-stage foaming. Experiments have demonstrated that the synthetic detergent concentration of secondary sewage effluents can be reduced by 80-90 percent by this single-stage foaming.

To increase the degree of separation, foam fractionation can be employed. There is an almost direct analogy between foam fractionation and fractional distillation. It is possible to recycle some of the collapsed foam back to a foam column as reflux. This washes out the bulk liquid held up in the column and enhances the separation possible just as reflux does in a distillation column. There are certain other possible innovations in foaming technology. Trace quantities of certain non-surface-active ions have been removed from solution through foaming by "complexing" them with surfactant materials. This same principle could be applied to remove non-surface-active or only slightly surface-active contaminants from waste streams. The waste stream could conceivably be "seeded" with some cheap, highly-surface-active material such as lignosulfonic acid, a waste product of the sulphite pulp industry. It is possible that foaming and adsorption would result in a highly effective "team" for the economic removal of organic impurities from water.

Freezing

Freezing is a comparatively new large-scale separation process which has received appreciable attention in conversion of saline waters. It may apply also to renovation of waste waters. In the direct freezing process, feed water is sprayed into a vacuum chamber operating at about 3 millimeters Hg absolute pressure. Part of the feed is flash evaporated, which produces a cooling effect and causes formation of fine ice crystals in the mother liquor. The ice slurry formed is pumped into a wash column in which it rises countercurrently to a small volume flow of wash water. The washed ice is then melted by condensation of the very same vapors which were removed from the vacuum chamber.

A disadvantage of the above direct freezing process is the tremendous vapor volume which must be conveyed and compressed. This is a consequence of the very low absolute pressure at which the system must operate. Use of a secondary refrigerant in direct freezing can minimize this problem. One problem in this system is contamination of the product by the secondary refrigerant and it has not been established how much residual refrigerant is permissible. Also, little is known of the fate of bacteria, virus, or even common organic contaminants within the freezing process.

An interesting extension of "conventional" freezing has been proposed in a special report prepared in the Advanced Waste Treatment Research Program. This process, termed "eutectic freezing", would be used to achieve very high waste concentration ratios by operating at the eutectic point of the feed, thereby rejecting from solution pure ice and precipitated contaminants simultaneously. It is theorized that this operation could be carried out at about -10°F, and would result in the continuous discharge of two slurry streams, one being ice to be melted as product and the other being a highly concentrated waste containing all impurities present in the feed, both organic and inorganic. The economics of such a process are not unfavorable in spite of the low process temperature because the eutectic freezer need be used on only a small fraction of the total plant throughput if it is applied to an already-concentrated brine discharged from some primary concentration stage.

Hydration

The hydration process is very similar to freezing, involving essentially the same phenomenon. A hydrate-forming gas, such as propane, is bubbled into a "reactor" (rather than a freezer) in which fine crystals of a solid hydrate are formed. The slurry is then pumped into a wash column in which it is washed with a small portion of the product water. The hydrate crystals are transferred to a decomposition chamber where the hydrate is caused to decompose by a change in temperature and/or pressure.

Product water is drawn off by simple decantation and the hydrate-forming material is sent back to the original reactor.

Gas hydration has certain themodynamic as well as practical advantages over freezing. These advantages may be increased by use of hydrating agents which form hydrates at temperatures closer to ambient conditions. Hydration may, in fact, be thought of as a high-temperature freezing process.

Oxidation

Although not strictly a "separation" process, oxidation is being considered because of its potential ability to destroy directly organic pollutants in aqueous solution. The problem is whether economical oxidation of organic substances can be performed in highly dilute solutions such as waste waters. Ozone, hydrogen peroxide, chlorine, chlorine dioxide, and other powerful oxidants offer possibilities. Electrolytic oxidation may also be applicable. Catalytic agents may be useful in employing atmospheric oxygen as an oxidant.

Ion Exchange

Small inorganic ions may be removed by conventional ion exchange in packed-bed, mixed-ion exchange columns. When the ion exchange capacity of the bed has been depleted, the feed is stopped and a regenerating solution passed through the bed. In this system provision must be made for disposing of the regenerating solution. More effective innovations of this process are possible. Electrical regeneration of ion exchange resins is of current interest as well as the possibility of synthesizing exchange resins satisfactory for both organic and inorganic ions.

Electrochemical Degradation

Appreciable evidence exists that many organic compounds are capable of participating in electrode reactions. The electrolysis of certain organic acids in aqueous solution can lead to complete decomposition. In addition to acids, many organic compounds including alcohols, aldehydes, carbohydrates, esters, and even hydrocarbons exhibit measurable conductivity in water. Electrochemical treatment appears to offer promise in advanced waste treatment and will be studied. The goal would be electrolytic decomposition of contaminants into simple innocuous molecules or merely conversion of relatively complex, refractory organics into a biologically "soft" or generally non-refractory form.

Electrolysis

Electrolysis of water, as a separation process, is perhaps more than any other approach considered in the "blue-sky" category. The process would involve the electrolysis of water to hydrogen and oxygen, followed by recombination of these gases chemically to create "new" water. Certainly, other electrode reactions could occur and the water generated might be contaminated, but based on exploratory experimentation and information from investigators of "life cycle" systems for space vehicles, it appears that pure hydrogen and oxygen are the most likely products of electrolysis of sewage effluents. This approach has one advantage over all others in that the waste water is being destroyed and recreated which should help overcome any "aesthetic barrier." A number of innovations are possible which may make the electrolysis process feasible in waste water renovation.

Permanent Concentrated Waste Disposal

There appear to be four general possibilities for ultimate disposal of concentrated wastes from an advanced treatment process. The first would be recovery of usable products from the waste. This is the most desirable solution but may prove the most unlikely. The conversion of a waste to a valuable product could eliminate the disposal problem and conceivably produce revenue from its sale which would help defray the expense of advanced waste treatment. A number of products suggest themselves: structural materials such as brick or building blocks, road paving, aggregate for concrete, fillers for various materials, soil conditioners, and insulation. Many cities could make use of recovered salts for street de-icing during winter months. The recovery of chemicals, and even extraction of pharmaceutical products, is not impossible. Fertilizer values present in municipal wastes are now utilized in many places. Sludge particles may have adsorptive properties, or these characteristics might be developed through proper activation, and could be reused in the waste water treatment process. Concentration of surfactants from the condensed foam of a foam fractionation process could be an important source of industrial detergents in the future. These and many other useful products may one day make the concept of multiple reuse apply not only to the water fraction of our municipal waste streams, but to the non-aqueous material as well.

The second method of ultimate disposal is discharge to some waste sink having no outlet. Included in such disposal would be: (1) dewatering and drying of the sludge with subsequent disposal as land fill, (2) discharge of brines to evaporation lagoons or to natural or artificial reservoirs set aside for this purpose, or (3) transport to the deep ocean. Transportation of residues to the disposal area would pose an engineering and economic problem in some instances. However, land fill of other community wastes is common practice and aqueducts are in use today which transport many millions of gallons of fresh water hundreds of miles. Therefore, concentrated wastes, composing perhaps only 1/100 or 1/1000 of these volumes, could conceivably be piped similar distances economically.

Subsurface disposal is a third possibility for concentrated waste disposal from an advanced waste treatment plant. Subsurface disposal may be either shallow deep. With shallow disposal reintroduction of the water fraction into usable ground water supplies may occur. Therefore, disposal by soil-spreading or shallow-well injection could be used only when provision is made for rendering potentially harmful contaminants innocuous before they find their way into usable supplies.

In deep-well injection, it is assumed that no contamination of existing or future water supplies could occur. The wastes are placed in strata so deep or so sealed that the wastes are forever removed from contact with human activity. Injection could be made into porous strata or into natural or artificial cavities such as salt domes, natural caves, or abandoned mines. The feasibility of underground injection as an important disposal method depends on the availability of suitable sites. The compatability of advanced waste treatment concentrates with various underground formations needs to be established.

The final possibility for ultimate disposal lies in converting the refractory contaminants to innocuous materials. In many cases this might be done prior to, and in conjunction with, recovery of products, dumping, or shallow underground disposal. Generally, it would be a chemical conversion process which would produce an effluent stream of suitable quality for release back into the environment. Biochemical processes of anaerobic digestion or aerobic fermentation may play a role. Few organic materials are completely inert to biological degradation under optimum conditions. Biochemical fuel cells, one of science's very newest developments, might be employed to recover energy for use in the process. Treatment by high-energy radiation has been suggested as a means for sterilizing wastes and even for catalyzing their oxidation to harmless materials. Incineration cannot be overlooked as a possibility and equipment is now available in which still-wet sludge may be sprayed directly into a combustion chamber. Wet oxidation of dissolved and suspended organic matter at high pressures and in the 500°-600°F range shows promise. Techniques such as this, which do not require dewatering of the waste sludge, may have appreciable economic advantage. If the heat value of oxidized materials can be recovered for use the day may come in which advanced waste treatment plants perform the functions now accomplished separately by refuse disposal, garbage disposal, and sewage disposal plants.

The choice of waste water separation process and of an ultimate concentrated waste disposal process will depend on the technological adequacy of the processes themselves. It is known that a number of processes are now capable of these functions but the problems of economics remain to be solved. By scientific research and application of new materials, new equipment and new principles, there is much reason to believe that economically and technically feasible advanced waste treatment processes will be developed which will permit the maximum reuse of the Nation's waters for all purposes.

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COMPREHENSIVE WATER QUALITY MANAGEMENT

General

The objective of comprehensive water quality management is to conserve and protect all beneficial uses of water. Its purpose is to assure an acceptable quality of water for a given use at the time and place where it is needed. These uses include both the withdrawals to support population growth and economic development, and the inplace uses associated with recreation and commercial and sport fishing.

Modern management strives for fish and wildlife propagation rather than mere prevention of gross fish kills. It denies that every waste producer has the right to pollute to the detriment of other water uses. It emphasizes prevention of pollution and conservation of water quality as well as improvement in quality that can be obtained through identification and correction of existing water pollution problems. Therefore, modern water quality management studies and surveys are much broader in scope and penetrate much deeper into basic scientific phenomenon than most stream surveys of the past.

The modern study includes economic and demographic investigations to project the place and time of future water needs, the quantity and type of wastes likely to be produced, and the points at which such wastes will be discharged. As well as their short range oxygen depletion and immediate toxicity, the long range toxicity and cumulative adverse effects of wastes singly or in combination with other wastes is determined. Permissable water quality for fish propagation and multiplication is determined in contrast to the quality needed merely to prevent fish kills.

To be effective, water quality management must be founded on knowledge of the basic natural laws governing hydraulic and hydrologic phenomena and natural decay and assimulation of pollution, both man-made and natural. It further involves the prediction of what will happen when and where additionalloads of man-made wastes are contributed as a result of population growth and industrial and agricultural expansion.

Armed with this fundamental information it is possible to plan for the comprehensive management of water quality in a river basin, and to develop the controls which will protect water from the ravages of pollution and provide for the maximum range of water needs. The modern water quality management plan has an element of perpetuity since it provides for continuous monitoring at critical points and immediate analysis of results, so that problems are identified and control actions put in motion before extensive damage is done.

The Problems Involved

In the past, the accumulation of knowledge concerning the fundamental physical phenomena involved in water quantity-quality relationships has been hampered by the following:

1. Single purpose and other limited surveys without simultaneous study in other sciences with the result that evaluation of the limited data available is of little help.
2. Lack of instrumentation for monitoring quality conditions continuously and in a sufficient number of parameters to provide an adequate insight into the fate of pollutants in our waterways, lakes and coastal waters.
3. Inability to achieve sufficiently broad areal coverage of chemical and biological reactions taking place simultaneously in a stream reach.

4. The extremely time-consuming traditional procedures available to accumulate even small amounts of information on the natural phenomena taking place in the streams and lakes, and the infrequency of opportunity to mount long-term investigations.
5. Lack of good tracer control mechanisms such as modern dyes or radioactive tracers.
6. The impossibility of predicting chemical, biologic and physical changes that take place in a stream or waterway under a set of circumstances different from those observed in a short run study.
7. Lack of practical means for measuring and evaluating minute quantities of inorganic and organic materials for properties which may be very damaging even in extremely small quantities.

Traditional Practices and Procedures

Under restrictions of limited resources and time for any particular investigation, it has been necessary to estimate the amounts of waste materials entering the streams from sewer outfalls and industrial sewers by taking random samples for analysis, and by measuring the quantity of liquid flowing at the time. From these samples and an estimate of total waste volume, the expected average amounts of pollution have been computed for periods of 24 hours, a week, a month, and a year. Only a relatively small number of quality parameters have been measured, usually biochemical oxygen demand, suspended solids and pH. These measurements have been relayed to the office engineers where cause and effect relationships have been calculated, largely on an empirical basis.

Surveys of this limited nature has been the usual basis for design of control systems needed to maintain water quality sufficient to satisfy immediate and predicted uses in the streams or lakes, and of treatment works costing millions of dollars. These procedures are typified by a minimum number of field observations and the application of empirical theory.

Projections of water use and population growth have been made largely on the basis of census data, with very little consideration of the various resources which can provide clues to future population and industrial growth of a community area or river basin. Reliance on historical data rather than growth potential has often resulted in under-estimation of actual growth and development.

Attention has been devoted largely to biologic and microbiologic observations. However, these have been quite limited because of the difficulty of successfully covering large stream reaches or lake areas simultaneously and continuously.

Studies of the physical phenomena such as stream velocities, lake currents and tidal action in estuaries have been accomplished by surface floats over relatively short periods of time. The results have generally been acknowledged to be inadequate. However, methodology for more precise observations was unavailable. Using the best practices and procedures available, and with limited data and existing methodology, it has been possible to improve waste treatment practices and to reduce pollution effects in many instances. However, the results frequently fall short of desirable quality objectives and apply to limited areas rather than the total water resource of a river basin. Furthermore, present practices are more suitable for controlling pollution after it has reached the critical point than for preventing its occurrence in the first place.

Use of New Materials, Equipment, and Techniques

In the period since World War II, scientific development in many fields has led to the development of new instrumentation, techniques, and materials which have been put to use and made comprehensive water quality management surveys and studies possible. These resources have enabled the engineers and scientists to increase the number, kinds, precision and coverage of observations of the physical phenomena occurring in the streams and waterways. Among the items which have increased scope and coverage of surveys and studies are the following:

1. Aerial photography.
2. Automatic continuous sampling devices.
3. Automatic recording devices for pH, dissolved oxygen, conductivity, chlorine, turbidity, etc.
4. Continuous reporting of automatically recorded water quality data through telemetering instruments, giving constant and instantaneous information to control centers.
5. Infra-red detection equipment for finding quickly and readily changes in the heat content of streams and lakes due to the inflow of warmer or cooler materials.
6. Laboratory instrumentation such as new gas chromatograph techniques, microbiologic procedures, and radiation instrumentation.

7. Computers
8. Analog models
9. Physical (hydraulic) and biologic models.
10. Dyes and radioactive tracers, and accompanying application techniques.
11. Mathematical statistics for analyzing gross numbers of observations.
12. Very slow velocity meters and direction finders for measuring water movements in lakes and coastal waters.
13. Procedures for rapid identification and differentiation of bacteria.
14. Bioassay techniques for detecting and quantitating toxic substances.
15. Activated carbon filters for concentrating trace organic compounds.
16. Spectrophotometer, automatic balances, automatic titrators, and bacteriologic membranes to increase the capacity of laboratories for analytic examinations.

Application of Automatic Technology

The application of automatic sampling devices by both government and industry in collecting, indicating, and recording of pertinent water quality parameters is rapidly increasing in importance as a tool of water quality management. Automatic and continuous sampling devices have made it possible to gather simultaneous samples of liquid from a wide area on a continuous basis with a minimum of cost and expenditure of scientific manpower. Automatic samplers can be activated by electric current from new type, long-lived batteries which energize electronic clocks and pumps, making it possible to synchronize sampling schedules over hundreds of miles of stream systems in accordance with a predetermined schedule.

Automated sampling is the result of a demonstrated need for continuous information on an immediate basis to detect significant instantaneous changes in surface water quality. The "grab sample" technique, even if expanded so as to cut down the time interval between samples to a very short period cannot guarantee the detection of brief slugs of pollution, or important diurnal variations and still remain practicable in terms of manpower and laboratory costs.

Many types of intermittent and continuous sampling devices are used to obtain water quality data. Composite samples may be collected by a power driven scoop mounted upstream from a weir designed so that sample volume taken on each rotation of the scoop is proportional to flow. The scoop may also be rotated at constant speed or timed to sample at fixed intervals. Chemical feed pumps with adjustable stroke and variable speed provide another means of securing representative samples of water for analysis. A solenoid valve with timer used in connection with a pumping system may be used to obtain composite samples.

Sensing probes for intermittent or continuous measurement of temperature, pH, and conductivity have been available for many years. Dissolved oxygen probes and sensors are examples of recent developments for water quality measurement. However, pH, conductivity, and dissolved oxygen probes, as well as other primary sensors, require further development for practical field use. Automatic continuous-flow, colorimetric, and titrametric analyzers for such parameters as phosphate, alkalinity, and total hardness are available for laboratory and plant use. Field sampling apparatus of this type is still in the developmental stage.

A primary need is to apply existing automatic devices and develop new equipment for the water quality measurement field where manual procedures are inadequate. A secondary need is to develop automatic techniques with an integrated system having an output readily adapted to high speed data processing techniques.

Currently, no single system is available that will automatically measure all water quality parameters. The fifteen water quality parameters listed below are currently being measured by analyses of grab samples in the Public Health Service's National Water Quality Network.

1. Alkalinity
2. Ammonia Nitrogen
3. Biochemical Oxygen Demand
4. Chlorine Demand
5. Chemical Oxygen Demand
6. Color
7. Dissolved Chlorides
8. Dissolved Oxygen
9. pH
10. Phosphates
11. Sulphates
12. Temperature
13. Total Dissolved Solids
14. Total Hardness
15. Turbidity

Applications of automatic instrumentation equipment for Network purposes are now being tested and evaluated for certain of these parameters for development of a continuous integrated system. Parameters such as conductivity, oxidation reduction potential and sunlight intensity are already being applied on an automatic basis by the Ohio River Valley Water Sanitation Commission and Interstate Commission on the Delaware River.

Automatic equipment needs to be developed for evaluation and testing for still other parameters, such as radioactivity.

Integrated System

Part of the goal of automatically recording some chemical and physical parameters has already been achieved through the development of a compact integrated system consisting of four phases, primary sensors, electronic analyzers, multipoint recorders, and telemetering. This system can continuously monitor and record the following basic parameters:

Conductivity
Dissolved Chlorides
Dissolved Oxygen
Oxygen Reduction Potential
pH
Sunlight Intensity
Temperature
Turbidity

The first units of this integrated system were developed for the ORSANCO for use on the Ohio River and its tributaries. It incorporates most recent advances in primary sensing techniques, advanced electronic circuit technology, and multipoint recording, and provides the capability for telemetering. This equipment is shown in Figure 14.

The integrated system employs a standard conductivity cell for measuring pH, oxidation reduction potential, dissolved chlorides, and dissolved oxygen. A pyrheliometer measures total sunlight intensity. A turbidimeter utilizing the principle of light reflectance is included. Sensors fabricated in an aluminum tube are employed for temperature measurement.

1. Primary Sensors - The sensors employed in this equipment are:

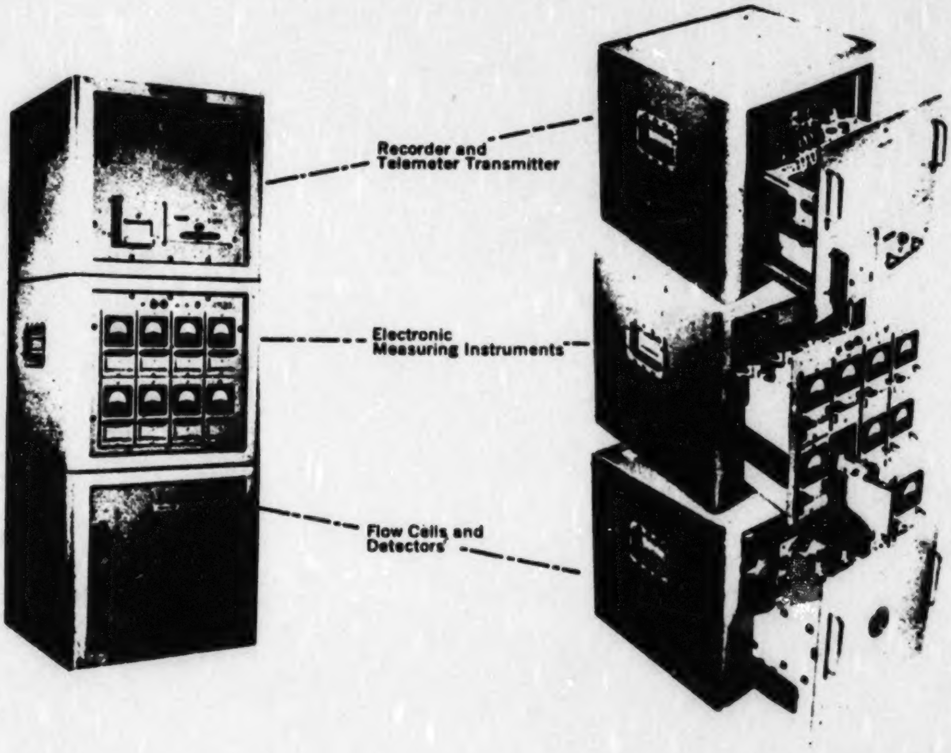


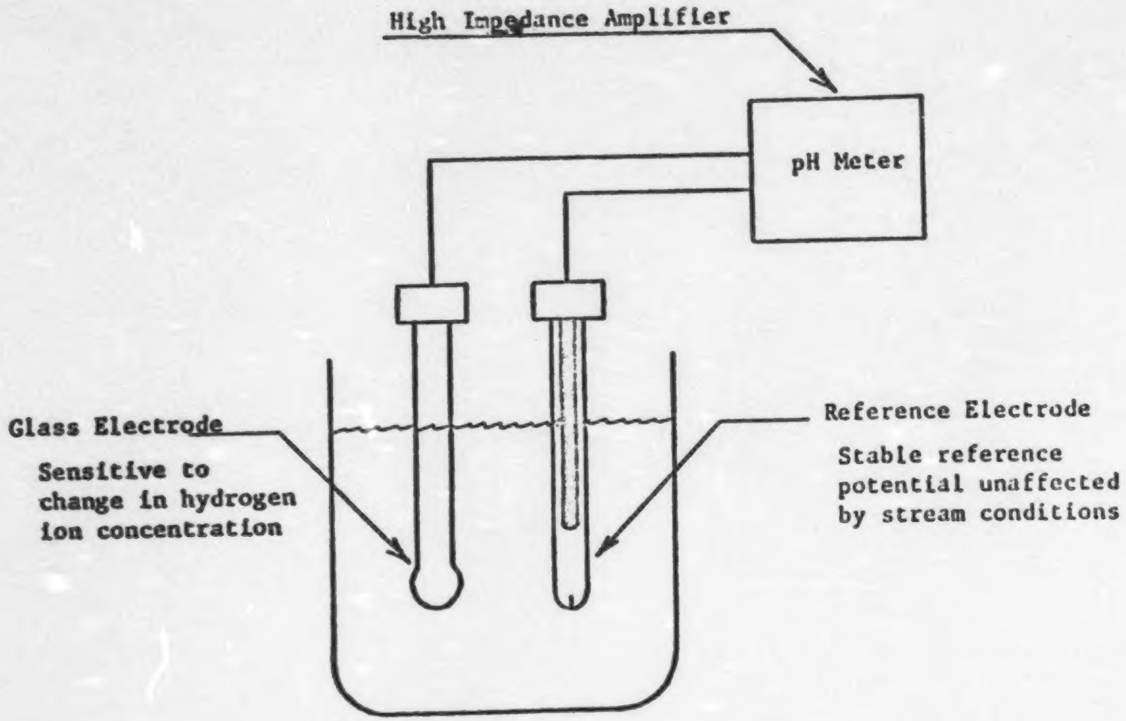
FIGURE 14 INTEGRATED WATER QUALITY DETECTION, RECORDING AND TELEMETERING EQUIPMENT

a. pH - For measuring pH, a glass electrode and associated reference electrodes are employed. A significant advancement in the measurement of pH has been the recent development of an improved glass electrode now presents an impedance of one to two orders of magnitude less than previous electrodes, so that greater accuracy in temperature compensation can now be effected, and also less critical electrometer input stages to the analyzer can be employed. (See Figure 15).

b. Oxidation Reduction Potential - The oxidation reduction potential measurement employes the same principles as the pH electrode except than an electron sensitive electrode replaces the hydrogen ion sensitive electrode. This electrode is generally made of a noble metal, such as platinum or gold.

c. Dissolved Oxygen - The Hays dissolved oxygen analyzer was one of the early techniques developed to replace the Winkler chemical method. It employed the paramagnetic properties of oxygen. Although the system does not easily become clogged with silt, it is rather cumbersome. A schematic diagram of the Hays Dissolved Oxygen Analyzer is shown in Figure 16.

A more recently developed electrode-type dissolved oxygen analyzer has been incorporated in the integrated system. (See Figure 17) Originally, this type of electrode employed a polyethylene membrane, but this has since been replaced by Teflon to filter all but the dissolved oxygen that is in the water. Dissolved oxygen passing through this


High Impedance Amplifier
pH Meter
Glass Electrode
Sensitive to change in hydrogen ion concentration
Reference Electrode
Stable reference potential unaffected by stream conditions

$$E = E^\circ - \frac{RT}{nf} \log H^+$$

$$= E^\circ - 0.0591 \log H^+ \text{ (at 25°C.)}$$

FIGURE 15 BASIC APPARATUS FOR pH MEASUREMENT

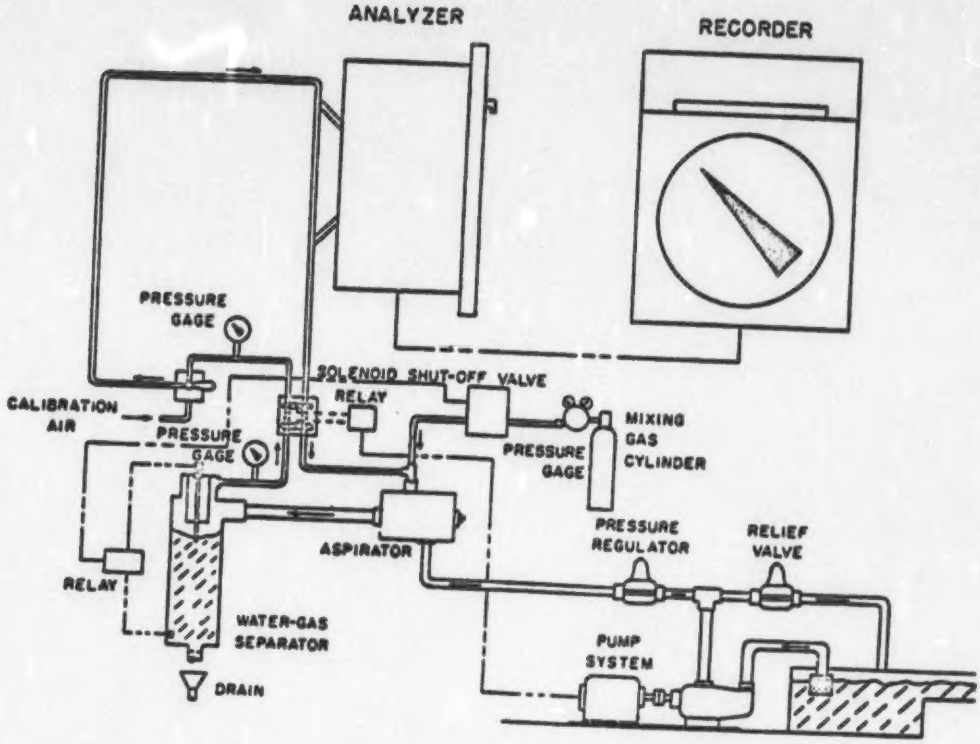


FIGURE 16 SCHEMATIC DIAGRAM OF HAYS DISSOLVED OXYGEN ANALYZER

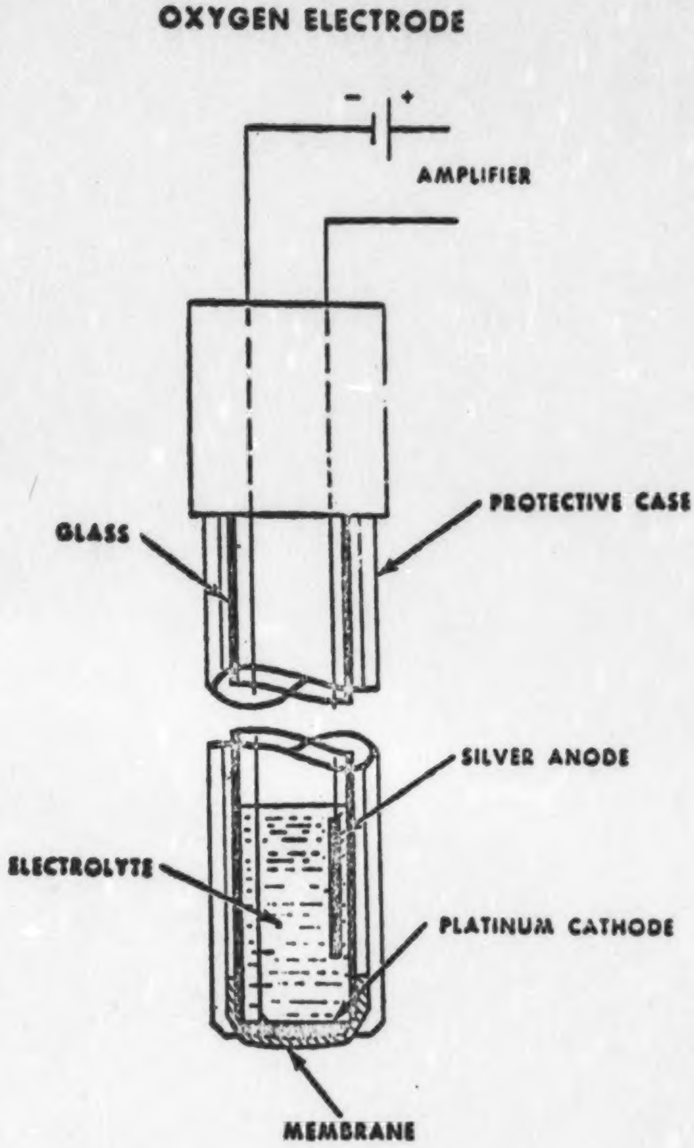


FIGURE 17 BECKMAN DISSOLVED OXYGEN MEASURING ELECTRODE

membrane is reduced at a platinum electrode, generating a current through a solution of potassium chloride. The resultant current is a direct measurement of dissolved oxygen. Additional developmental work is required, however, since this electrode may become coated with silt or algae growth after varying periods of operation and is affected by sulphur dioxide and several of the halogens. Recently a gelatin-type electrolyte has replaced the liquid electrolyte permitting more flexibility in the mounting of the electrode.

d. Temperature - Several years ago the thermocouple was employed for measuring temperature. This produced a voltage output which was generally a nonlinear function of temperature. Subsequent developmental work in solid state physics has produced the thermistor, and more recently the sensistor. The sensistor, when employed in a Wheatstone bridge, produces an output signal which is a linear function of temperature. Sensistors are employed in the integrated monitoring system both for temperature compensation and as primary temperature sensors.

e. Turbidity - There are essentially two basic methods for measuring turbidity: light absorption and light reflection. The integrated system includes a turbidimeter employing the principle of light reflection from the surface of a water sample. One obvious advantage in this method over the absorption technique is that there are no windows to be coated by silt so that true calibration is retained over a longer period. (See Figure 18)

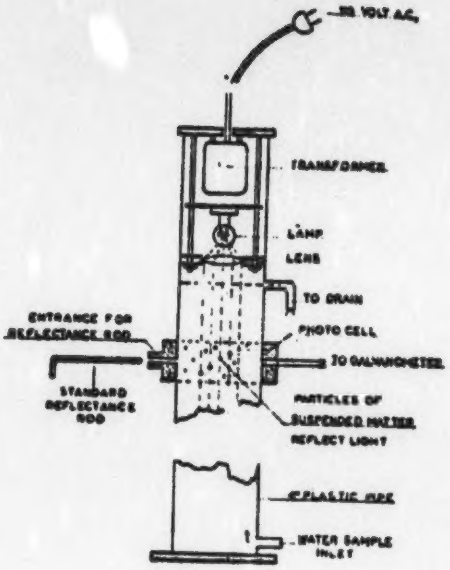


FIGURE 18 LOW-RANGE TURBIDIMETER (HACH)

In newer systems, it would be desirable to integrate the measurement of turbidity with the measurement of color. In general, a turbidimeter employing light absorption can be used to measure either turbidity or color but not both simultaneously. Although no work has been done on this, some thought has been given to the use of different colored rotating filters, one of which would be glass with little absorption capacity, to permit detection of selected colors as well as turbidity with one device.

f. Sunlight Intensity - For measuring sunlight intensity a pyrheliometer is employed consisting of two concentric circles 10 mils and 5 mils in diameter respectively. The outer circle is coated with magnesium oxide and the inner circle with lamp black. Each circle is electrically insulated from the other. Incident sunlight causes a temperature difference which generates a voltage in a thermocouple. One wire is an alloy of 60% gold and 40% paladium while the second is an alloy of 90% platinum and 10% rhodium. The device produces 90% or better of its output when exposed to radiation having wave lengths between 0.35 micron and 2.6 microns. This limitation is imposed upon the device by a sodium lime glass enclosure.

g. Conductivity - Measurement of conductivity is made by applying an AC voltage across a pair of platinum electrodes. The cell forms one arm of a Wheatstone bridge and the unbalanced output is amplified and rectified by the analyzers, and recorded as conductance.

Alternating current is employed in this measurement to prevent polarization of the cells. A line frequency of 60 cycles has been shown to be satisfactory, although in several cases frequencies of 400 and 1000 cps have been employed. The current carrying ability of a solution depends upon the ions present and their mobilities. Mobility is temperature dependent so that temperature compensation is required and is effected by the application of sensistors.

Although present conductivity devices are satisfactory for measurements below 10,000 micromhos, and in "rather clear waters," difficulties have arisen in measurements an order of magnitude higher, so that additional research in conductivity measurements is desirable.

2. Analyzers - The integrated system equipment employs the more recent electronic operational amplifier technology in the analyzer phase of the integrated system in preference to conventional AC amplifiers. This technology provides greater stability and reliability, and lends itself to modular design, thereby facilitating maintenance.

Research is now being carried on to determine the feasibility of employing solid state devices in the analyzer phase of the integrated system. One primary difficulty of the application of solid state devices is their sensitivity to temperature change. Current through a solid state device is exponentially related to temperature. A possible engineering solution to this dilemma might be controlled temperature environment for the analyzer section, although advanced research in solid state physics may also provide a solution.

3. Recorders - The integrated system employs one multipoint strip chart recorder which displays all parameters on a single chart, a technique facilitating visual analysis and reducing the number of instruments requiring maintenance and replacement.

4. Telemetering - The transmission of water quality data from remote localities to a central monitoring and processing facility can also be provided in an integrated automatic data acquisition system. There are two general methods for transmitting signals from a monitor to a central locality, radio-frequency and telephone lines.

The radio frequency or micro-wave transmission employs carrier frequencies which are modulated by the telemetered signal. The transmitter may be keyed by a form of information which can cause a contact closure or which can be used to vary the frequency in an oscillator circuit. These alternatives are classified as either amplitude or frequency modulated techniques. Micro-wave telemetering is generally directional in that its transmission is focused on the receiving antenna at a distant point. As a general rule micro-wave transmission is limited to line-of-sight operation for dependable results. Repeater stations may be employed where longer distances are required.

When telephone lines are employed several methods of data transmission can be used.

a. Techniques can be employed which involve the conversion of the quantity to be measured into an electric current proportional to the variable measured.

b. Voltage transmission methods vary the voltage at the receiving end so that it is proportional to the quantity measured.

c. Impulse telemetering consists of the transmission of square type pulses which may or may not be uniformly spaced. One method of impulse telemetering produces a single pulse for each unit of the parameter measured, transmitted at equal time intervals. In other systems the interval between impulses may be proportional to the parameter measured, and the pulse amplitude held constant.

d. Another form of telemetering employs frequency techniques. In this approach the frequency of a carrier is directly proportional to the amplitude of the parameter measured. This type of telemetry is employed by the ORSANCO equipment for transmitting pH and other values in which a carrier frequency between 5 cps and 15 cps is employed. Thus, 5 cps represents 0 pH, 10 cps represents a pH of 6, and 15 cps represents a pH of 12. Telemetering makes it possible to eliminate a great deal of manual translation, which is often accompanied by errors that are costly and hard to find.

Data Processing

The increasing sophistication of computers and their adaptability has made it possible to utilize fully, large quantities of data from continuous observations of natural phenomena, and to summarize and analyze them in days--only a few years ago the job would have been virtually impossible of achievement. The use of computers, therefore, has greatly refined the theoretical approaches, has provided greater insight into physical phenomena, and has enabled a reduction in errors incurred during manual manipulation of large quantities of data. It has made it possible to greatly increase the number of quality parameters which can be summarized and used in making judgments regarding control measures and management problems.

Analog computers are a very useful tool. The analog has made it possible to simulate a stream system by reducing the observations made to an electronic circuit which reacts to stimuli as does the river or body of water, the stimuli in the analog computer being that corresponding to and applied by the manipulator in accordance with the observed condition in the river. This has made it possible to inject additional variables or increased amounts of stimuli to gain further insight and to predict what will occur in a stream or lake under different sets of circumstances.

1. Analog to Digital Conversion - As previously noted, recorded data must be processed either manually or automatically. To

provide the capability for automatically processing data from an integrated system, analog to digital conversion is required. There are essentially two devices used for analog to digital conversion: (a) electro-mechanical devices called encoders, and (b) analog to digital converters which employ either magnetic amplifiers, vacuum tubes, or solid state devices. If the conversion occurs at the monitor, it is possible to produce the output as binary coded decimal information on magnetic tape, as BCD information on punched paper tape, or as decimal information on binary cards.

Although the magnetic tape output device is fastest and directly compatible to most digital computers, it is the most expensive and most delicate. Research in the application of magnetic tape under field conditions would be desirable to exploit the two advantages of speed and computer compatibility.

A more economical but slower method for producing digital output is the paper tape technique. There are basically two paper tape methods: (a) binary coded decimal in serial fashion, and (b) binary coded decimal employing 16 channel tape. In the latter technique a single row of holes represents one specified number, and in the former technique a block of holes 6x8 in size would represent a specific number. The 16 channel paper requires a special tape reading device for producing punched cards. A third alternative to producing information for digital computer processing employs an analog to digital converter and a mechanical summary punch or key punch.

Although this technique would produce cards that would be directly compatible to digital processing, the equipment employed would be quite cumbersome and transfer of cards from monitoring station to control data processing point would present a problem for continuous water quality monitoring.

Of the three alternatives, punched paper tape at this time seems to be the cheapest, the most reliable, and the simplest from a field operation view, though it is the most time consuming from a data processing point of view.

A peripheral operation from paper tape to cards generally is required before punched paper tape can be utilized by a computer.

2. Digital Computers - For processing water quality data, various types of digital computers can be employed. These include the IBM series 704, 1401, 1620, 650, the Honeywell 400 and 800, and similar systems.

At the present time, the Robert A. Taft Sanitary Engineering Center is employing a Minneapolis-Honeywell 400 Digital Computer for data processing. The basic system consists of a central processor, four magnetic tapes units, a high speed printer (900 lines per minute) and a high speed card reader (650 cards per minute). The central processor includes an arithmetic unit, a control unit, one block of memory (12,288 decimal digits - which can be expanded to a total of 49,135 decimal digits) and an independent console. Figure 19 shows the Minneapolis-Honeywell 400 digital computer facility as installed at the Sanitary Engineering Center.

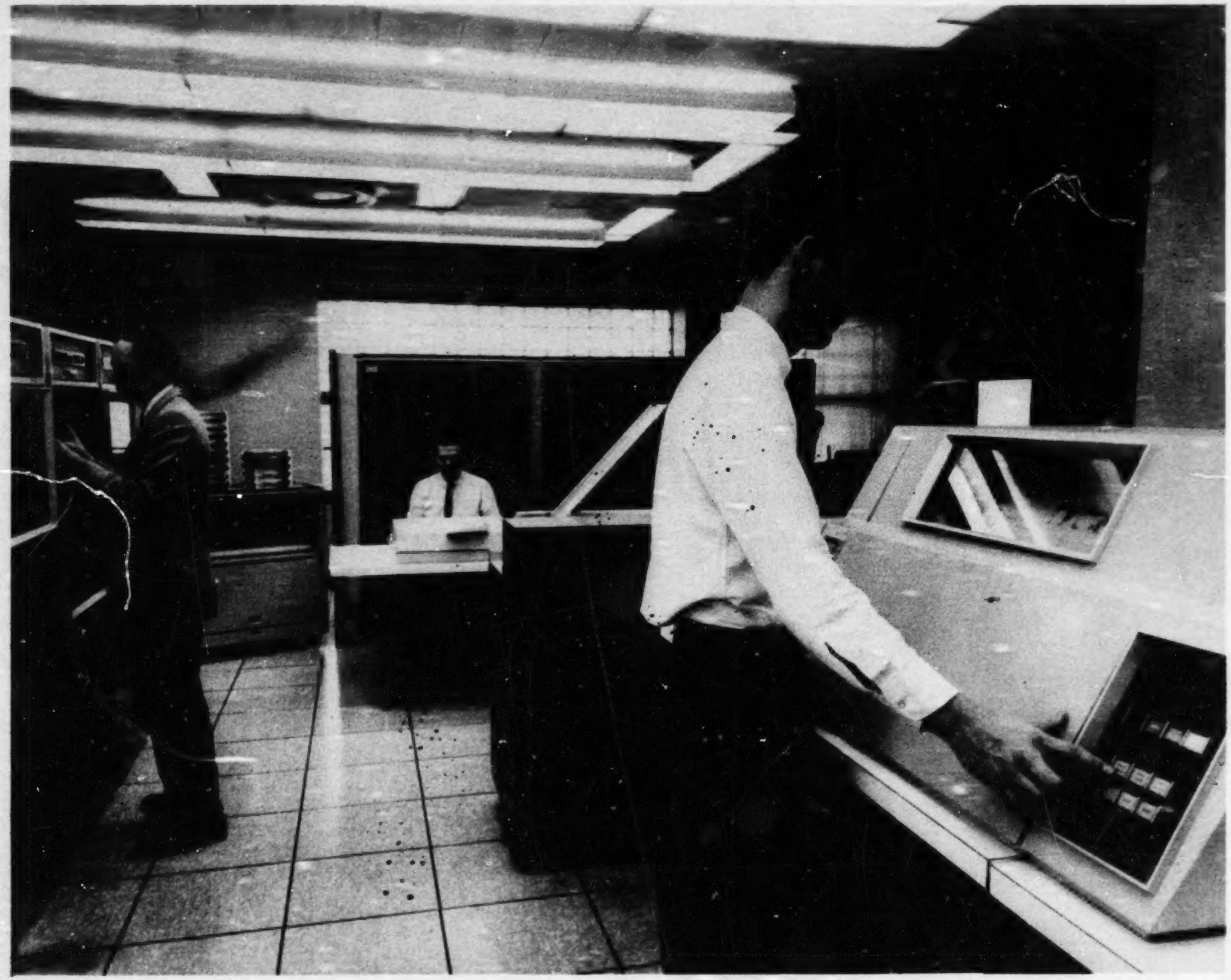


FIGURE 19 DIGITAL COMPUTER AT TAFT SANITARY ENGINEERING CENTER

3. Computer Programs - There are two basically different approaches possible in water quality data processing: (a) accumulate data over a period of time, and then process the information to determine correlation and long-term trends; and (b) maintain constant surveillance over the data and carry out a variety of operations on it immediately whenever given parameters exceed predetermined magnitudes.

While both approaches require access to computers for proper utilization and application of the data, the techniques will be basically different.

a. Data handling for trend development - To evaluate water quality data for this purpose, several programs consisting of composites for many sub-routines are required:

(1) A sub-routine for determining maxima and minima on a parametric basis.

(2) A sub-routine for determining logarithmic probability.

(3) Sub-routines for determining cross correlation between all parameters.

(4) Sub-routines for extrapolating previous data.

(5) Sub-routines by which observed damage to fish and other forms of life can be correlated with data on water quality.

(6) Sub-routines for calculating one parameter from two or more others.

Advanced digital computer programming techniques, which employ recently developed computer languages and eliminate time-consuming basic machine language, will be employed to develop these programs.

b. Data handling for continuous monitoring - Where continuous monitoring is required, and where there will be a concurrent need for telemetry, immediate access to a computer will be necessary. Processing data on an emergency basis, when one or more parameters exceed previously defined limits, suggests different types of digital computer programs from those listed above. These would include:

(1) A sub-routine for determining the effect on points downstream of reaching these predetermined levels.

(2) A sub-routine designed to assist in locating the cause of these "abnormal" values.

(3) A sub-routine for determining who should be alerted in order that corrective or preventive action may be taken.

Thus, in the case of true monitoring, if a specific group of parameters exceed allowable limits, data collected for a short interval of time will be processed immediately and the source of the excess localized. Simultaneously, proper authorities, such as water company superintendents and local health authorities, would be notified.

Specifications

Detailed specifications are being formulated to extend the capabilities of automatic water quality data acquisition and processing equipment.

The objective of the specifications will be to obtain integrated systems having the capability for automatically determining conventional parameters from both the chemical and physical groups. This will undoubtedly require modifying existing automatic electro-potential and titration systems and the development of automatic chemical analyzers that are not yet available.

The specifications will also encourage the development and production of simplified analog to digital conversion systems for producing an output adaptable to digital computation. To provide for more reliable transmission capabilities, studies of existing systems are being made and the results incorporated into these specifications.

Other New Developments

The use of physical and biologic models is presently in the developmental stage. The objective is to produce a simulated condition on the basis of observations made directly on the water body and related to the model, and to predict changes that will occur as a result of the application of variables. The models hold great potential for predicting these changes, and thus for planning effective water quality management. The models employ the most sensitive of micro-instrumentation, new dyes, and chemicals. Many kinds of cements, plastics, metals, instruments, and photographic and electronic gear are employed in their construction. A permanent record of occurrences in the model is produced, which forms the basis for preparation of operating schedules of water quality management systems.

One of the very great problems in the study of large bodies of water has been determination of the dispersal and ultimate fate of wastes. Techniques for using fluorescein dyes have improved greatly with the development of a fluoromometer which can be mounted on a moving boat, allowing observations of the dispersal of the dye to be made continuously over a wide area. The dye is an excellent representative of the waste material dispersed in the water body and behaves in much a similar fashion. Radioactive tracers have been found very useful in ground water studies, particularly isotope iodine 129 which is extremely long-lived and can be readily determined both radioactively and chemically. The age of water can also be determined by evaluating the tritium concentration. Water falling since the first H bomb explosion in 1954 contains concentrations higher than those flowing prior to that time. This bench mark provides an excellent starting date for measuring the age of water and is invaluable in calculating the distance traveled and the amount of pollutants carried through that travel period.

Aerial photography and techniques for making observations quickly, directly, and permanently are rapidly improving and are being applied to locating sources of waste outflow in the streams and for determining the dispersion of these wastes in large bodies of water. The usefulness of photography has greatly increased with the development of film highly sensitive to light and color refractions.

Infra-red detection equipment is extremely sensitive to heat differentials and is being developed and used for locating liquid waste discharges and their dispersal in lakes and rivers. Infra-red ray reflections are translated into electronic signals, and viewed and recorded instantaneously on a cathode ray tube.

The recent development of frictionless bearings made of plastics having the same specific gravity of water and development of magnetic clutches has made possible the production of instruments capable of measuring water velocities 1/100th of those usually measured by traditional equipment. These velocity measurements can be translated by magnetic clutches, which have little or no drag on the instruments, to electronic recording devices and further transmitted to telemetering systems at remote control centers. The measurement of currents as low as 1/100th of a foot per second near the bottom of Lake Michigan have been made, thus allowing for the first time scientific appraisal of the mass movements of water in the Great Lakes systems and in many of our estuaries.

The use of the adsorptive capacity of activated carbon to concentrate minute quantities of organic materials has had a far-reaching effect on our capabilities for measuring the great variety of these materials which find their way into the waterways. A large, measured volume of water is pumped into the filters. After a given volume of water has been filtered, the filter is subjected to a solvent examination and the materials concentrated, analyzed, and measured. Plastics and special non-corroding metals have been developed for the activated carbon filtration practices. Filters placed in the pumping systems have been specifically designed for river bank installation, and for operation without manual control over long periods of time. Carbon filters have been used to identify pesticides of all kinds as well as innumerable oils and certain organic chemicals which find their way into streams. The carbon filter sampling equipment and extraction apparatus are shown in Figures 20 and 21.

New instrumentation developed for laboratories has greatly increased the scope and sensitivity of analytical work. Gas chromatography has made it possible to measure quantitatively and qualitatively very minute quantities of synthetic organic materials, such as insecticides. In the past there have been no measurement methods except through time consuming and costly biologic assays, and these do not provide the necessary

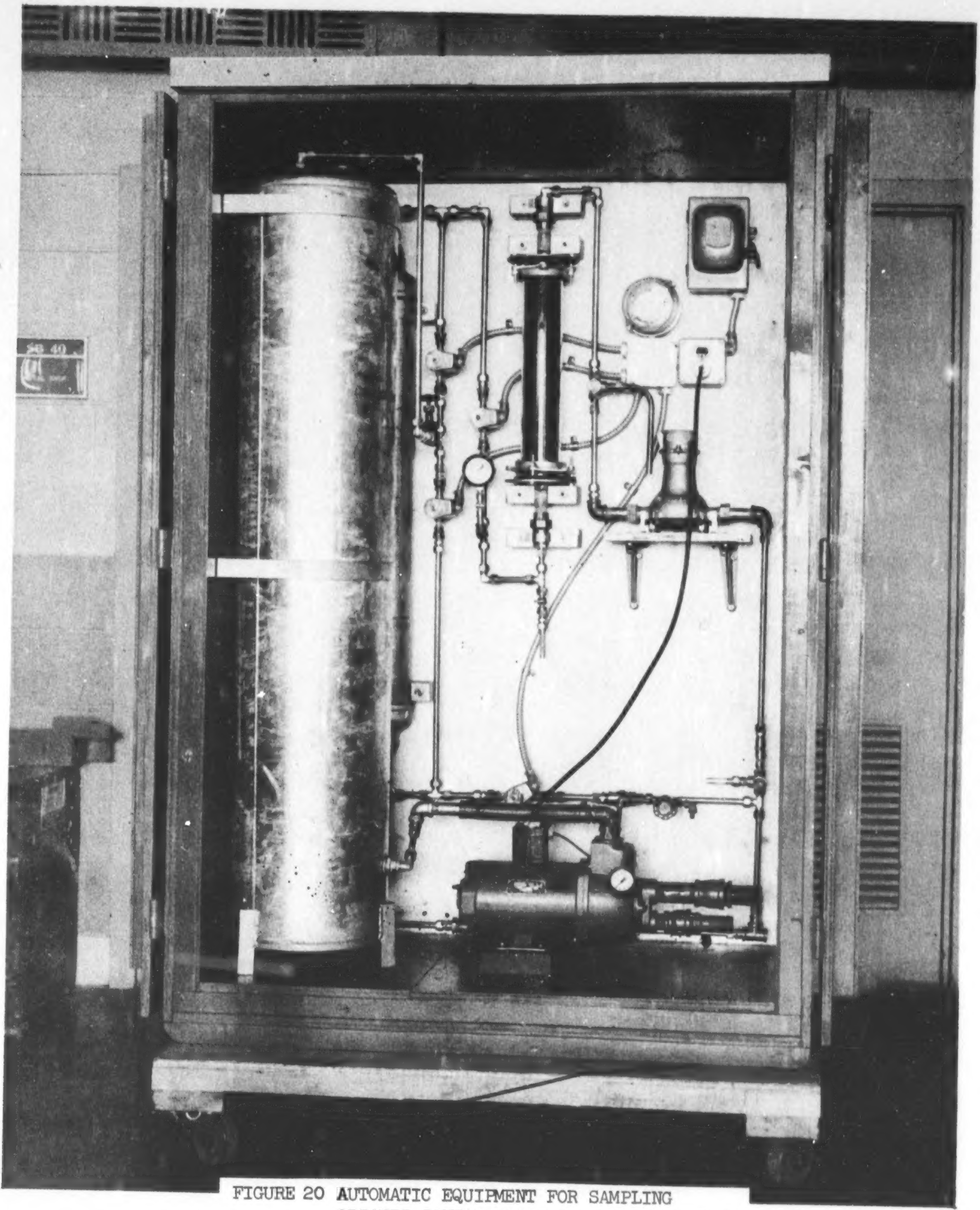


FIGURE 20 AUTOMATIC EQUIPMENT FOR SAMPLING ORGANIC CONTAMINANTS IN SURFACE WATERS

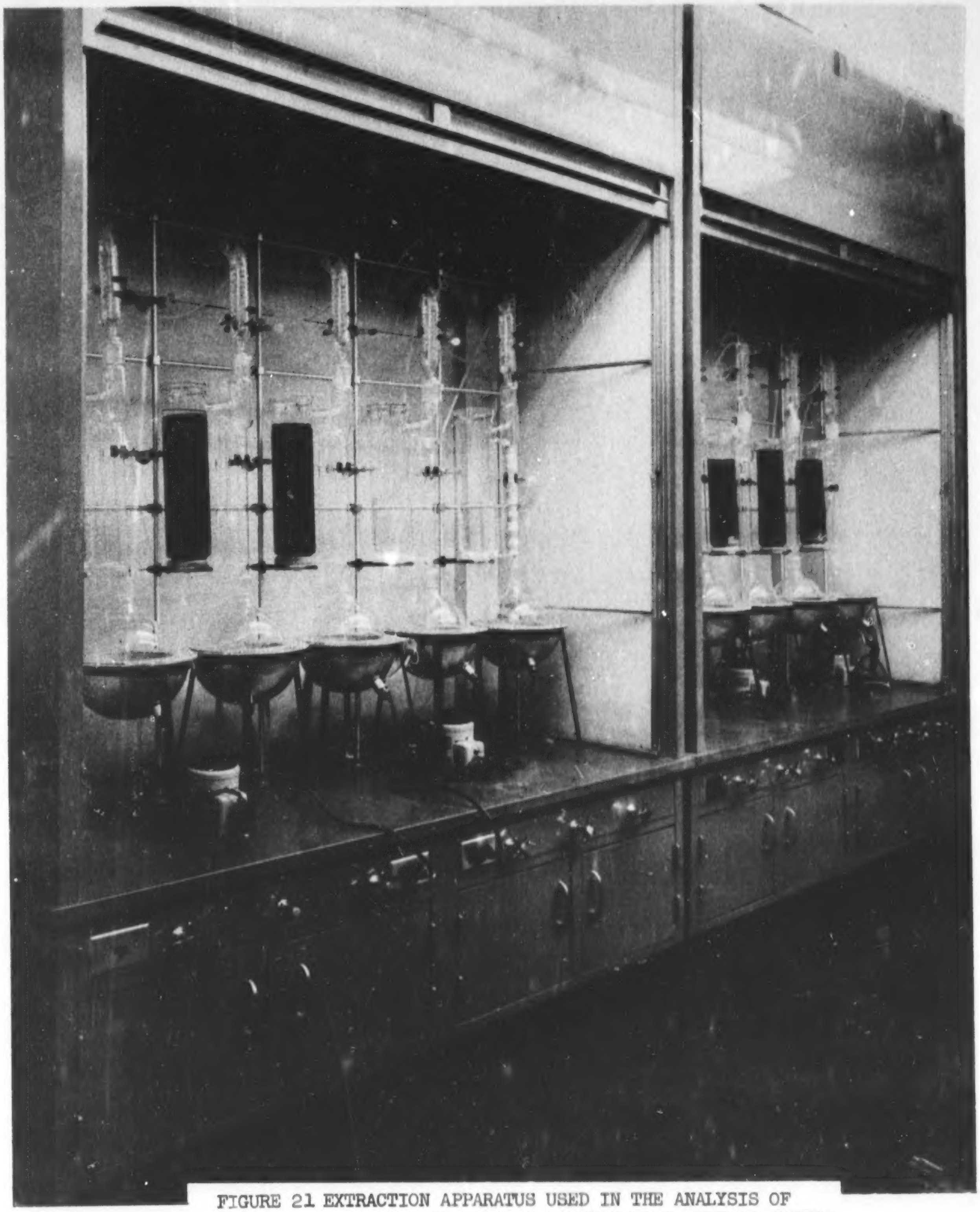


FIGURE 21 EXTRACTION APPARATUS USED IN THE ANALYSIS OF ORGANIC CONTAMINANTS SAMPLED FROM SURFACE WATERS

analytical preciseness. New radiation instrumentation has made it possible to measure quickly and accurately the three kinds of radiation present, and to reduce the time required for computation.

In addition to new analytical procedures, new analytical instruments have greatly increased the efficiency and production of the laboratory. The spectrophotometer has made possible the identification of large numbers of substances in a very short time per sample. Automatic balances have greatly speeded examinations. Automatic titrating devices employing electric eye cells have increased the production of laboratory scientific personnel nearly 10-fold. These uses of new techniques, equipment and materials have given the present-day water pollution control scientist a tremendous potential for increasing his scope, coverage, and depth of examination. They have enabled him to simulate conditions which may occur over long periods of time in the future. This makes it possible to develop plans for not only controlling pollution but for preventing damages to water uses and to develop further techniques and systems for maintaining water quality in whole river basins in accordance with a pre-determined norm.